Impact Assessment Regime for Sustainable Agricultural Innovation Processes: the Triple Helix System of Innovation for Sustainability (THIS)

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I

Abstract

Sustainability-oriented innovation targets efficiency in the use of natural resources and mitigation of negative environmental impacts. Due to greater financial uncertainty in connection with ecological risks, such innovation is less likely to be successfully adopted in a market environment.

The overall objective of this study is to analyse innovation processes in agriculture, and to assess their ability to integrate market-driven as well as ecosystem-oriented activities across different levels of relationship interaction. This study was conceived to overcome a domain approach in agriculture by developing a framework for the analysis and management of sustainability-oriented innovation processes in agriculture: the Triple Helix System of Innovation for Sustainability (THIS). It is set to enhance the generation, diffusion and utilisation of new knowledge generated by interaction between agricultural practice, research and policy.

The framework was effectively divided into three levels of relationship interaction, based on a main component identified in case studies. Each level represents the main aspect of institutional relationships relevant to the negotiation of market versus ecosystem, including 1) technological, 2) organisational, and 3) governance aspects. The negotiation of sustainability goals is conducted by translating the overarching global United Nations Sustainable Development Goals (SDGs) to the substantive focus of innovation in each case. Methods sensitive to the context of individual case studies were applied to achieve results specific to each case.

Each level of relationship interaction reveals specific research questions, addressing for example the consideration of sustainability impacts at the beginning of an innovation process (the front end), management functions required to organise and steer an innovation process, and the potential for integrating indicators for sustainability in policy regulation and governance. In applying THIS, the innovation process is shown to require a greater presence of policy representatives at the technological and organisational levels. This could be achieved for example by broadening project funding to include policy representatives into projects. Furthermore, the validation of positive results under consideration of ecological risks requires experimental research and testing in projects with temporal flexibility.

This study contributes to the debate on viable forms of innovation management for goal-oriented innovation processes. The application of THIS achieves to address risks and to accelerate the process in the face of additional uncertainty posed particularly by environmental aspects characteristic to innovations developed in the agricultural sector. Finally, this study shows how the requirements of iterative management can be reflected in organisational structures for institutional support.

II

Kurzzusammenfassung

Nachhaltigkeitsorientierte Innovationen unterstützen die Effizienz bei der Nutzung natürlicher Ressourcen und die Minderung negativer Umweltauswirkungen. Aufgrund einer größeren finanziellen Unsicherheit im Zusammenhang mit ökologischen Risiken sind solche Innovationen in einem Marktumfeld weniger wahrscheinlich.

Das übergeordnete Ziel dieser Studie ist es, Innovationsprozesse in der Landwirtschaft zu analysieren und ihre Fähigkeit zur Integration marktgetriebener und ökosystemorientierter Aktivitäten über verschiedene Ebenen zu beurteilen. Die Studie wurde konzipiert, um einen Domainansatz in der Landwirtschaft zu überwinden. Dafür wurde ein Rahmen für die Analyse und das Management von nachhaltigkeitsorientierten Innovationsprozessen in der Landwirtschaft entwickelt: das Triple Helix System der Innovation für Nachhaltigkeit (THIS). Es soll die Verbreitung und Nutzung neuer Erkenntnisse aus der Interaktion zwischen landwirtschaftlicher Praxis, Forschung und Politik unterstützen.

Der Rahmen wurde basierend auf einer Fallstudienanalyse in drei Interaktionsebenen eingeteilt. Jede Ebene repräsentiert einen Hauptaspekt institutioneller Interaktion, der für die Aushandlung von Nachhaltigkeitszielen über den Markt und das Ökosystem relevant sind, darunter 1) technologische, 2) organisatorische und 3) Governance-Aspekte. Die Aushandlung wird durch Übersetzung der wesentlichen Schwerpunkte auf die lokale Ebene durchgeführt. Wesentliche Grundlage dafür sind die übergreifenden Nachhaltigkeitsziele der Vereinten Nationen für nachhaltige Entwicklung (SDGs). In der konkreten Umsetzung wurden für jede Fallstudie kontext-sensitive Methoden angepasst.

Auf jeder Ebene ergeben sich spezifische Forschungsfragen: in der Vorplanung (Front End), in der Einbindung von Managementfunktionen, und in der Berücksichtigung von Indikatoren für Nachhaltigkeit in politischen Gesetzentwicklungsprozessen. Die Anwendung von THIS zeigt, dass der Innovationsprozess eine stärkere Präsenz von Politikvertretern auf technologischer und organisatorischer Ebene erfordert. Dies könnte beispielsweise durch eine Ausweitung der Projektfinanzierung auf politische Repräsentanten in Projekte erreicht werden. Darüber hinaus erfordert die Validierung positiver Ergebnisse unter Berücksichtigung ökologischer Risiken experimentelle Forschung in Projekten mit zeitlicher Flexibilität.

Die Analyse, die sich aus der Anwendung von THIS ergibt, trägt zur Debatte über tragfähige Formen des Innovationsmanagements für zielorientierte Innovationen bei. THIS dient somit als Rahmen, um Innovationsprozesse zu beschleunigen und die zusätzlichen Unsicherheiten bei den im Agrarsektor entwickelten Innovationen frühzeitig zu berücksichtigen. Schließlich zeigt diese Studie, wie sich die Anforderungen eines iterativen Managements in Organisationsstrukturen für institutionelle Unterstützung widerspiegeln können.

III

Abbreviations and Definitions

Abbreviations

DG	Directorate General of the European Commission
DIS	Durable Integration Structure
EC	European Commission
ESS	Ecosystem Services as described in the Millennium Ecosystem Assessment (MEA 2005)
EU	European Union
IA	Impact Assessment
IP	Integrated Project
MEP	Members of European Parliament
NoE	Network of Excellence
SDG	Sustainability Development Goals according to United Nations (UN 2015)
SME	Small and Medium Enterprise
THIS	Triple Helix System of Innovation for Sustainability

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Introduction

1.1 European Agriculture in Transition

In recognition of prevalent trends in the use of natural resources, the agricultural sector is being urged to react to societal demand for sustainable production methods. Radical systemic changes based on sustainability-oriented innovation are required to provide alternatives to increasingly resource-intensive production with global and local impacts. Questions, however, arise in regard to the organisation of transformation, and the necessary combinations of institutional interaction to organise new types of production and distribution.

Global political, socio-economic and environmental changes affect local farm systems, with the most significant drivers being human population growth, increasing global energy demand and climate change adaptation (EC 2015, EC 2013). The development of the agricultural sector in reaction to market development and political frameworks has led to farm management practices that in sum exceed the capacities of natural resources (Rockström et al. 2009). The drivers that have led to over-utilisation of resources are not expected to diminish in the nearby future. With world population projected to surpass nine billion in 2050 (UN 2011), agricultural production is estimated to increase by approximately 60% in the next 30 years. The projection is based on the aggregate value of production increases between 2005 and 2050 which was obtained by multiplying physical quantities of demand and production by price for each commodity, and summing up over all commodities of the crop and livestock sectors (Alexandratos and Bruinsma 2012; FAO 2006). In Europe, the over-utilisation of land is already evident, and land suitable for crop production is becoming a limited resource. Finland, for example, is requiring more agricultural land to meet its population's needs for agricultural produce than is available within the country, resulting in the export of production to other countries (Sandström et al. 2014). An expansion of cultivated land outside of Europe together with an expected shift in consumption patterns to more meat-based diets and greater caloric intake will expand trade from and to developing countries. Price changes and volatility due to these changing trade patterns will likely further affect the European agricultural sector (Knudsen et al. 2006).

The combination of the above sources of pressure causes farmers in the European Union to increase input factors as well as farm size and to become more specialised, mechanised and reliant on intensive production to keep up with an increasingly globalised food supply chain. Where adaptation is not possible, the sector faces farm shrinkage and decimation, particularly of small and medium size farms. A phenomenon of the 'disappearing middle' has been identified in many European countries. The main development paths are seen to be: 1) disappearance of small farms and land abandonment, 2) specialisation of small farms and better market integration, and 3) diversification and combination of on- and off-farm income strategies (Davidova 2014). Farmers respond to the economic pressures and structural changes with an increasing interest in innovative strategies, such as the creation of niche market products and regional food labels, cultivation of specialty crops and diversification of crops and products (Suess-Reyes and Fuetsch 2016; Darnhofer et al. 2010). Successful examples are rooted in local incidental entrepreneurial ventures and favourable frame conditions.

Amidst an ongoing search for financially reasonable and worthwhile strategies, producers and processors in the agriculture and food sectors are increasingly sensitive to unintended side effects resulting from agricultural intensification and specialisation (Stoate et al. 2009). Strategies of extensification in one locality may lead to land conversion and intensification at other localities, thereby causing further environmental detriments such as biodiversity loss or emission increases (Garnett et al. 2013). Strategies of intensification will eventually lead to daunting challenges in terms of resources (water, energy and land use) and impact (droughts, diseases, health impacts and movement of capital) that in the end also affect individual farms. Finding viable approaches in response to soil conservation and water use efficiency along value chains constitutes an additional incentive for farmers to pursue innovative strategies (Kulak et al. 2013; Mandryk et al. 2012).

Against this background of increased awareness of environmental impacts of production, farmers reach out to sectoral and regional partners as well as research organisations to explore strategies for mitigation and avoidance of unwanted side effects. Sustainable solutions require state-of-the-art knowledge, including novel scientific research in the life sciences, to adequately address the complex interactions and feedback between drivers (Bloch et al. 2016; König et al. 2013; Le Gal et al. 2011; Meynard 2013; Giller et al. 2008).

1.2 Sustainability-oriented Innovations in Agriculture

Sustainable development is an anthropocentric process that enables a social system to maintain its integrity based on an anticipation of changes in the social, environmental and economic spheres. The social system has the ability and will to adapt to the changing requirements without collapse (Folke et al. 2002; Nooteboom 2007). In the Brundtland report, sustainable development is defined as "*development that meets the needs of the present without compromising the ability of future generations to meet their needs*" (WCED 1987).

In the agricultural sector, the formulation and implementation of sustainability together with subsequently established political strategies, regulations and governance has a retroactive effect on production processes. It triggers farmers to invest in adaptation strategies leading to invention and innovation that aim to resolve deficiencies in sustainability. The establishment of new products and services is expected to have an effect on social, environmental and economic dimensions of welfare, visible in institutional, regional or sectoral changes. Where the outcome is measurable, it can be communicated between policy and practice. Political goals for sustainable development in agriculture include the impetus to achieve food security, ensure sustainable consumption and production patterns, protect, restore and promote sustainable use of ecosystems, and halt biodiversity loss (UN 2015). These goals are laid down in the 2030 Agenda for Sustainable Development driven by the United Nations as an action plan to address fundamental challenges to social systems in the environment worldwide.

Improved strategies for sustainability in agriculture are based on a combination of scientific and experiential knowledge of natural-resource management at crop, field and farm levels (Wezel et al. 2014; Meynard 2013; Kropff et al. 2001). Examples of agro-ecological interventions include integrated pest management and alternative crop protection measures that include use of antagonist species (Buurma & van der Velden 2016; Vänninen et al. 2015), interventions in nutrient-cycling to improve coupled crop-livestock systems (Moraine et al. 2014), implementation of rotational grazing and no-tillage systems for soil organic matter accumulation (Manson et al. 2016; Nelson et al. 2014; Titonell et al. 2012) and precision farming (Busse et al. 2014; Eastwood et al. 2017). All examples are expected to support sustainable development particularly through efficient use of natural resources and mitigation of negative environmental impacts. Furthermore, all examples have been found to require systemic innovation at the farm and enterprise levels, meaning a combination of changes in production, resources allocation and farm business management implemented in a structured and systematic way.

Primarily, sustainability-oriented innovation is defined as being directed towards sustainable processes in which resources use and waste production remain within environmental limits (Foxon & Pearson 2008). Different terms are used, often interchangeably. Examples include 'eco-innovation', 'sustainable innovation', 'environmental innovation', and 'green innovation' (Schiederig et al. 2012). In part, however, the terms can be clustered around certain keywords and a main focus of research (Franceschini et al. 2016) (**Table 1**). Additional terms with insufficient data for clustering include ‘eco-efficient innovation’, ‘low-carbon innovation’, ‘innovation for sustainability’, ‘socio-ecological innovation’ and ‘externality reducing innovation’.

Table 1 Epistemic Clusters of Research Communities for Sustainability-oriented Innovation., adapted from Franceschini et al. (2016).

	Keywords	Main focus	Example reference
Eco-innovation	eco-design, eco-efficiency, co-evolution of sectors, lead markets, life-cycles, multi-criteria assessments	Technological trajectories	Rennings (2000), Beise & Rennings (2005)
Sustainable innovation	transition in socio-technological systems, functional dynamics, regime shifts	Socio-technological systems	Elzen & Wieczorek (2005), Hekkert et al. 2007)
Environmental innovation	sector competition, relationship between environmental regulation and market efficiency, effects and determinants of innovation, ecological modernisation of production processes	Regulatory and governance aspects	Malerba et al. (2007), Rennings et al. (2006), Porter & van der Linde (1995)
Green innovation	competitive advantage, resources-based management, supply chains, new product development	Management aspects	Chen et al. (2006), Hart (1995)

Overall, sustainability-oriented innovation encompasses the market-based classification of innovations as products, processes, marketing strategies and new forms of organisation and management that is proposed in the Oslo Manual by the OECD (2005) for an interpretation of innovation data (e.g. Rennings 2000). At the technological level, sustainability-oriented innovation is more dependent on use of ecological principles and ecosystem knowledge as compared to market-driven innovations. At an organisational level, they rely on a coordination of additional experts as well as an integration of additional knowledge to achieve an effective design of products and processes. Thus, a knowledge basis needs to exceed manufacturing and market knowledge to include environmental impacts and interrelationships. Policy framework conditions are found to influence and provide incentive for innovations, and their adoption, through requirements specifications and legal compliance. The establishment of positive-frame conditions is particularly relevant and time consuming for sustainability-oriented innovations because success is dependent on an assessment of unintended or irreversible environmental impacts and ecological risks. Overall, sustainability-oriented innovation is laden with extra complexity compared to market-driven innovation, and therefore products and services more often fail to achieve sufficient value creation for adoption and market establishment.

In business management, uncertainties in the technological development of market-driven innovations are often illustrated by a “valley of death”. The phrase refers to the period of time between the phase of product development and the phase of successful product placement on the market that is necessary to generate financial returns. It is in this phase that new business ventures face a high risk of failure due to limited cash flow as well as risk-averse behaviour on the supply side, and by potential customers or investors. Supply-side support in pre-commercialisation phases, and particularly capital input from the public sector, are one common way to address underinvestment and non-economic uncertainties related to sustainability-oriented innovation (EC 2009). Additional funding can provide the means for mitigating information gaps, acquiring soft assets such as additional expertise, patents or trademarks, or achieving a thorough knowledge of the market environment and consumer demands.

In the agriculture sector, the role of resolving uncertainty is to a large part attributed to research. The main aim is to avoid trial and error approaches on the way to entrepreneurial success. Agro-ecosystem research can generally be expected to contribute to sustainable development by engaging in processes leading to problem-solving at the farm and enterprise levels (e.g. Duru & Therond 2015; Levidow et al. 2014). Systems approaches provide for knowledge-based management options designed around extrapolation of land use trends, exploratory testing of innovative interventions and identification of policy instruments required to realise particular land use options (Schut et al. 2014; Kropff et al. 2001).

Associated therewith is the aim to achieve an expected environmental benefit next to entrepreneurial success. Sustainability-oriented innovation in the agriculture sector has been found to require additional investments in skills, knowledge and cooperation as well as in a motivation to change at different systemic levels. Knowledge investment can thus become relevant at the level of farmers and local stakeholders (e.g. Titonell et al. 2016; Meynard 2013), at the level of network relationships (e.g. Klerkx et al. 2010), at the level of public and private institutions (e.g. Triomphe & Rajalahti 2013; Hall et al. 2007), or at the level of regulations (e.g. Santilli 2013) and decision making, e.g. at national or EU policy levels (e.g. Birch et al. 2011; Grunwald 2008).

On each level, the additional input needed for sustainability-oriented innovation has to be adjusted to the specific requirements of an agro-ecosystem and the type of planned technological intervention (Geels 2005). Coordination of knowledge transfer and communication of outcomes of change between the different levels becomes a relevant issue in sustainability-oriented innovation management in agriculture. This multiple level perspective stands in contrast to a more entrepreneurial business management perspective for market-driven innovation, where individual entrepreneurs react to push factors such as new materials, regulations or standards (e.g. Beise & Rennings 2005), pull factors such as consumer demand (e.g. Malerba et al. 2007) or efficiency in resource allocation (e.g. Hart 1995).

Regarding the necessary additional knowledge investment, different types of research become relevant during innovation development, leading from fundamental research over applied and experimental research to consultancy, training and advice. Where multiple actors are engaged in the innovation process, interactive learning takes place with regard to regulatory, organisational as well as technological processes of change in all stages of development. Institutional frame conditions and legislative regulation measures, for example, can strongly influence options and chances of market entry and market success, as is seen with innovations in renewable energy (Horbach 2016). Thus, linear conceptions prove to be insufficiently descriptive where innovations emerge from networks of actors in an iterative process (Knierim et al. 2015; EU SCAR 2012).

New coordination approaches for the iterative organisation of knowledge input are influencing the role of research towards innovation support. This is especially relevant in a strongly environment-related land-use system, where local, experiential and tacit knowledge is required. This leads to a development where innovation brokers and mediators take up a position as research coordinators at the science-practice interface. Building on network relationships, systemic analysis and adaptive management, intermediaries act as co-developers of products and services, or as expert advisors for monitoring, evaluation and assessment of innovations (Klerkx et al. 2012). Most often, the required cooperation for knowledge and technology transfer between actors is managed either in sporadic ways, by individually-driven personal-pioneer support or trial-and-error approaches. The path to utilisation and eventual market sustenance is thus experienced as especially uncertain, time-consuming and tedious.

European policy frameworks have acknowledged the extreme complexity in developing sustainable agro-ecosystems in their current programmes. As a consequence, innovation has re-emerged as a high-priority topic in European Union agricultural policy and research (EC 2016; EU SCAR 2013). Prognostic instruments based on coordination approaches are required and need to be capable of assessing potential development pathways as well as identifying the added value of new products, production methods and distribution approaches in regard to sustainable development. Knowledge input is particularly required for estimating actual and future consumer demand as well as for intelligent risk-taking. It is expected that technical solutions alongside environmentally and socially sensitive combinations of farming and business approaches can help the concept of sustainable development out of a merely theoretical discussion on guiding principles. Emphasis is put on a wider diversification of knowledge sources, on the strengthening of networks and multi-actor platforms, the development of new data aggregation, analysis methods and design of suitable policies. The implementation of bottom-up thematic networks based on the immediate need of farmers for potential solutions is an essential component of current funding programmes for transdisciplinary research. The European Innovation Partnership Programme funded by the European Commission under the Horizon 2020 Research Programme is one current example (EIP-Agri 2016).

1.3 Coordination of Innovation Processes in Agriculture

In line with the increasing political awareness for the above-mentioned systemic obstacles in innovation processes, practical innovation support has developed from one-dimensional, linear step-by-step formulations to approaches that focus on the interaction between actors (Triomphe & Rajalahti 2013). Previously, institutions working toward favourable conditions in innovation and development, such as the World Bank, had for many years embraced more linear conceptions of development. With a focus on the technological development of products, an innovation process was described rather straightforward, leading from research and extension to practice. Extension services were widely supported to facilitate knowledge and technology transfer, e.g. via experimental development and prototyping. In recent years, the influence of a multiplicity of actors and their interaction with the wider environment on innovation processes was gradually more recognised and integrated into strategic considerations (World Bank 2012; Hall et al. 2006). Currently, approaches related to Innovation System concepts (Lundvall 2010; Freeman 2008; Lundvall 2002) dominate innovation support processes in science and policy. The Innovation System is addressed as "*a network of organisations, enterprises, and individuals focused on bringing new products, new processes, and new forms of organisations into economic use, together with the institutions and policies that affect their behaviour and performance*" (Hall et al. 2006, p. vi). The Innovation System concepts have gained from Actor-Network Theory (e.g. Latour 1987) on the one hand, and Agricultural Knowledge and Innovation Systems (e.g. Röling 1990) on the other. While the former has contributed to the analysis of the emergence, functioning and structure of innovation networks, the latter have contributed to development-oriented analysis of network links and interactions between actors engaged in knowledge utilisation for problem-solving.

Innovation Systems concepts have been applied at international, regional, local and sectoral scales. They take consideration of time scales by distinguishing different phases of development. All approaches involve groups of actors concerned with goal-seeking changes with the aim to improve the establishment and management of gap bridging institutions.

Analysis of uncertainties and defined gaps have led to an implementation of innovation platforms (Kilelu et al. 2013) or intermediaries (Klerkx et al. 2012) that foster feedback and learning via multi-actor frameworks and adaptive management. Multi-actor frameworks have developed from socio-technical systems approaches, e.g. the so-called "transition arena" as a central niche space for change (Kerkhof and Wieczorek 2005). They have also been applied to management processes for the negotiation of competing claims in natural-resource management (Giller et al. 2008). Adaptive management draws on environmental assessment and management studies, and was developed for improved natural-resource management (Holling 1978). It comprises the identification of management options and adaptation strategies, the evaluation of options by stakeholder interaction and the development of guidelines for intervention (e.g. Reed et al. 2007). The experimental and goal-seeking approach in adaptive management has also been applied to policy processes, where it was found to facilitate collaboration and the development of incentives in institutional structures (Folke et al. 2002; Lee 1999).

In an attempt to summarise the underlying holistic idea of these concepts, which is related to the ability of collaborative networks to adapt to a non-linear environment, the Innovation Ecosystem has appeared in innovation literature. The conception of Innovation Ecosystems specifically highlights the co-creation of values through collaboration, and is therefore increasingly used in innovation management studies that focus on multi-faceted intervention rather than product development. The term also highlights the relevance of internal, self-correcting structural changes within the innovation system, where government takes over an enabling role (Smorodinskaya et al. 2017; Triomphe & Rajalahti 2013).

1.4 The Triple Helix System of Innovation

The **Triple Helix System** moves onward from the network perspective of the previously mentioned concepts to a conception of co-creation by actors from different sectors on a continual basis over time. In addition to the Innovation Ecosystem, the Triple Helix System adds a further dimension to drive innovation development from science to markets through interaction between universities, industries and government. A helix model stands for the evolution of multiple linkages between different actors at different stages of an innovation process (Etzkowitz 2003; Leydesdorff 2000; Etzkowitz & Leydesdorff 1998; Leydesdorff & Etzkowitz 1998; Leydesdorff & Etzkowitz 1996).

In comparison to the concepts described in the previous chapter, the Triple Helix System allows greater consideration of a strong role of governance. The focus is on relationships between the pre-defined unilateral domains of university, industry and policy. It assumes a constant fixed distance between the domains, and no fixed end point to transition. Nevertheless, it allows for various degrees of selective mutual adjustment according to purpose, e.g. in a change of actors during the course of an innovation process. The Triple Helix System has been in development since the 1990s, and draws on works in dynamics and evolution in technology development by Lowe (1982) as well as reflexive self-organisation and functional differentiation of societies within a system by Luhman (1975). It is applied as an analytical framework to analyse functional interactions and institutional relationships.

Circulation along the helix between the domains of research, industry and government is considered a basic premise of development. The Triple Helix System goes beyond linear step-by-step models by highlighting four types of evolutionary transformation: 1) the internal transformation within each spiral, 2) the influence of one spiral on each of the others, 3) the co-evolutionary interaction of all three spirals resulting in a new overlay of institutional structures, and taken together 4) a recursive effect of these entities on society as a whole (Etzkowitz & Leydesdorff 1998). An analysis of co-evolutionary interaction and its translation into a strategic plan can result in a new organisational format for science-technology-policy interaction. The process of translation along generic development stages is described by Etzkowitz and Klofsten (2005) as follows:

Genesis: creating the idea for a new format of institutional interaction;
Implementation: developing infrastructure to realise the new format;
Consolidation: improving functional efficiency through adaptation of the activity profile;
Self-sustaining growth: ensuring adaptive genesis and sustenance by constant renewal and modification of the system.

The triple helix approach has been applied to numerous processes for innovation support, whereby the roles of research, industry and government were found to vary in type and intensity across geographical scales (Fitjar et al. 2014), countries (Rieu 2014) and backgrounds (Hessels et al. 2010). Variation in the research spiral, for example, can occur due to different researcher perceptions of stakeholder relevance across research fields. It can also be influenced by the specific homogeneity or heterogeneity in the set of actors from each domain in a particular case of interaction (Hessels et al. 2010). In more autonomous research fields with an unspecified and heterogeneous set of end-users, stakeholder interaction is seen as a trade-off to publications (e.g. N-cycle biochemistry), while in research fields concerned with applied questions interaction is seen as beneficial to achieving relevant research output, access to additional data and credibility (e.g. crop breeding). The behaviour of researchers in a certain research field is therefore a relevant factor in the assessment of relationship interaction with the research spiral, since it can influence the selection of actors and define their expected input in the process.

A body of literature has also emerged that brings together a variety of approaches to capture, map or measure the triple helix relationships in regional or sectoral contexts. Assessment is possible, for example by using synergy between spirals (mutual information) as an indicator (Leydesdorff & Park 2014; Leydesdorff & Fritsch 2006; Leydesdorff et al. 2006). In the field of science, technology and innovation, the overlay of triple helix interaction can be described, for example, with functions of wealth creation, knowledge production and normative control, thereby focusing on information flows in knowledge-based innovation systems measured by entropy. Other approaches focus on capturing and organising collaborative activity, thereby relying on economic indicators such as patents or income flows. Basically, this leads to a differentiation also in triple helix approaches being either more flow-oriented or more structure-oriented (Meyer et al. 2014).

The Triple Helix System has developed in parallel to other relevant concepts spanning from linear to open innovation. For an overview describing the relationship interaction for innovation at case study level, based on collaborative knowledge production and with an aim to overcome market failures and systemic gaps, see Villarreal & Calvo (2015). One example worth noting here for its relevance in domain-spanning approaches is the New Production of Knowledge (Gibbons et al. 1994). This concept differentiates self-defined and self-sustained disciplinary knowledge production (Mode 1) from problem-oriented interdisciplinary knowledge production in short-term task-force-like teams (Mode 2). The notion of a new relationship between science and society has since greatly influenced a rise in transdisciplinary and multi-actor approaches as well as an increased focus on economically and socially relevant research themes. One main difference to the Triple Helix System is found in the analytic approach. The New Production of Knowledge framework denies a distinction between the different domains of science and technology, industry and academia, society and knowledge. The Triple Helix System, in contrast, argues for related yet distinct spheres with internal events in each, and interrelations between them. Its key claim is that institutional structures become ill-adapted to current situations, new structures co-evolve to temporarily resolve the mismatch, before again the new structures become themselves out of match. The Triple Helix System thereby addresses the concrete problem of "endless transition" within research, industry and government by stimulating response to changing cognitive, technical, economic and international trends in a cyclic process (Shinn 2002; Etzkowitz & Leydesdorff 2000).

The cyclic process was found to bring together the idea of creative destruction proposed by Schumpeter (1942) and the idea of renewal proposed by Kirzner (1999). Furthermore, the **Triple Helix System** resolved some of the key flaws in previous innovation systems approaches, such as the difficulty to draw system boundaries (Ranga and Etzkowitz 2013). While the Innovation Systems approach strives to overcome institutional distances between sectoral organisations, the Triple Helix System views innovation as a process where cognitive distances between single disciplinary perspectives are overcome. This is done by establishing a shared knowledge base which is built on the exchange and mutual uptake of corresponding norms and values, and of which collaboration between actors is a central activity (Frenken 2016). The notion of the knowledge base as a foundation for evolutionary innovation development has become relevant in development programmes, particularly in bringing together scientific progress in the life sciences with economic development and sociocultural adaptation. One European example is the European Knowledge-Based Bio-Economy initiative aiming for a new approach in the use of biomass for food, feed, energy and industrial material production.

In further development of the Triple Helix System, a set of institutional components with interlinked relationships and predefined functions as input resulted in the **Triple Helix System of Innovation** (Ranga and Etzkowitz 2013). The main function of the Triple Helix System of Innovation is the generation, diffusion and utilisation of knowledge. Thereby, the key features of the Triple Helix System can be synthesised to fit the institutional relationships driven by a specific innovation process with set targets. In this manner, the Triple Helix System of Innovation provides a flexible yet explicit framework to analyse the interaction between actors who are involved in an innovation process aimed towards resolving a specific problem.

From this perspective, the consolidation of new models of institutional interaction is driven by the co-development of actors in spaces of action and knowledge exchange. Actors and spaces are defined by the innovation's stage of development and market requirements. The application of the framework can help to identify existing blockages or gaps in the innovation process, and generate new combinations of knowledge and resources to advance innovation theory and practice, especially at the regional level.

The Triple Helix System of Innovation is characterised by three conceptual elements described as components, relationships and functions (Ranga & Etzkowitz 2013, p. 238):

- **Components** include individuals, institutions or agencies generally described as university, industry and government, in a defined boundary, e.g. a regional or sectoral innovation system. A distinction is made between (a) R&D and non-R&D innovators; (b) 'single-sphere' and 'multi-sphere' (hybrid) institutions; and (c) individual and institutional innovators.

- **Relationships** result in new knowledge combinations, either generated by the efforts and capacities of components, or by technology transfer. Relationships can be e.g. technology transfer, collaboration and conflict moderation, collaborative leadership, substitution, and networking.

- **Functions** can be described as the creation of knowledge space, innovation space and consensus space. Achievement of innovation depends on four types of capabilities: 1) strategic capability (e.g. selection), 2) organisational ability (e.g. coordination), 3) functional ability (e.g. technical functionality) and 4) learning ability (e.g. adaptation).

Opportunities for research are seen in more applied work, particularly evaluation and impact studies. Case studies are one suitable way to address complex social phenomena in a research area that is largely determined by contemporary questions in a practice-oriented, solution-seeking environment (Yin 2014). A case study approach is also suited to address the how and why of goal-oriented development. This study proposes analysis of a **T**riple **H**elix System of **I**nnovation for **S**ustainability **(THIS)** aimed at achieving sustainable agro-ecosystems through the use of selected case studies.

1.5 Objectives

The overall objective is to analyse a Triple Helix System of Innovation for Sustainability in agro-ecosystems by using selected case studies in the agricultural sector. The seven case studies represent combinations of institutional organisation and their differently-weighted relationships, thereby exemplifying 1) technological, 2) organisational, and 3) governance aspects of an innovation process.

Therewith the intention is to prove the applicability of the triple helix approach in sustainability-oriented innovation processes through a coherent structuring of institutional interaction between agricultural practice, research and policy. The question is, whether the technological, organisational and governance aspects of interaction constitute fundamental hierarchical levels in the analysis of sustainability-oriented innovation processes. This would imply that the innovation process can be specifically addressed and attributed via these levels. Furthermore, the innovation process may be accelerated by identifying supporting and hindering factors at each level in the THIS.

Following a case study approach, the aim is to analyse the interlinkage between market-driven processes and sustainability-oriented activities especially in

1) early planning stages of innovation development (**Chapter 2.1**),
2) prototyping and field testing (**Chapter 2.2**),
3) innovation development targets (**Chapter 2.3**),
4) managerial functions in research networks (**Chapter 2.4**),
5) organisational structure of research networks (**Chapter 2.5**), and
6) the integration of environmental aspects into policy frameworks (**Chapter 2.6**).

1.6 Organisation of Research

The study is structured into an introduction (**Chapter 1**), three research sections I-III, each addressing one level of triple helix interaction (**Chapter 2**), discussion (**Chapter 3**) and conclusion (**Chapter 4**).

SECTION I comprises Chapters 2.1–2.3, addressing the technological aspects of innovation-related interaction at the level of agricultural practice. In this context, **Chapter 2.1** develops a foresight framework to steer the integration of short term innovation goals and long term sustainability goals at an early planning stage. By applying this framework to four case studies in northern Germany, conceptual challenges and requirements are derived for different types of sustainability-oriented innovation. Each case study is embedded in an actor network of an emerging innovation system. **Chapter 2.2** further details one of these case studies by describing field experiments conducted to assess the invention of a biological control agent for *Verticillium* regulation in strawberry production under real production conditions. Based on a crop-relative rating system used in strawberry production, the ecological impact of the invention can be quantified in terms of crop pest mitigation. In **Chapter 2.3**, the value perceptions of actors involved in innovation development are analysed based on expert interviews conducted in two case studies. The case studies focus on the reintroduction of dual-purpose poultry production and the development of decentralised thermal production using surplus biomass from marginal wetlands. Content analysis and case comparison lead to a better knowledge of the actors' motivation to pursue the development of sustainable innovations, which can be used for negotiation and planning.

SECTION II comprises two chapters addressing the organisational aspects of innovation at the institutional level of research. **Chapter 2.4** looks into managerial functions needed in interdisciplinary project-based research for policy-oriented knowledge. Differences between product-oriented research management and entrepreneurial production management are explained at the example of a European Framework Project. **Chapter 2.5** proceeds to explore suitable organisational structures and elements of coordination needed to maintain a research network beyond the funded phase of a research project. This is conducted with the example of a European Commission funded Network of Excellence (NoE).

SECTION III contains one chapter addressing the policy aspects of triple helix interaction for sustainability-oriented innovations. **Chapter 2.6** looks at European Commission policy impact assessment as one potential mechanism to ensure the consideration of sustainability in the process of defining new European policies. A document analysis of impact assessment reports issued in 2014 is used to analyse specifically the consideration of environmental criteria next to social and economic criteria. The evidence is used to evaluate the integration of criteria with specific reference to the Ecosystem Services Concept.

In **Chapter 3** the results are discussed with a focus on the specificities of innovation development within the agricultural sector, concluding with **Chapter 4**.

1.7 The Triple Helix System of Innovation for Sustainability (THIS) Conceptual Framework

This approach looks at the technological, organisational and governance aspects of an innovation process that aims to achieve sustainable agro-ecosystems via changes in agricultural production and distribution. The targeted innovation process is defined by agricultural practice (including partners positioned upstream and downstream in the value chain), research and policy. The conceptual framework for the THIS is presented in **Fig. 1.**

The innovation process generally starts with an invention developed by innovators within or outside the research domain. The motivation is a perceived need for alternatives to increasingly resource-intensive production systems that have impacts on the socio-economic situation of farmers but also society in general. The effort to minimise environmental impacts through sustainability-oriented innovation is confronted with a confluence of short and long term risks to the achievement of economic viability. In this context, it is assumed that to achieve sustainable agro-ecosystems, the balance of market-driven activities and sustainability-oriented activities needs to be reconciled to achieve maximal contribution to sustainability.

The study therefore focuses on the requirements needed to bring both goals together: to achieve widespread diffusion and utilisation of an innovation as well as to approach sustainability in the system affected by it. It will look at the drivers and activities at different levels of relationship interaction required to reach both goals. It will also focus on the reconciliation (in Figure 1:) of aims oriented towards the market on the one hand and ecosystem services on the other.

To reduce the complexity of the innovation process, this study will identify the requirements that facilitate the development of sustainability-oriented innovations, and analyse the supporting factors across the different levels of relationship interaction. By applying THIS, the study looks at three systemic interactions taking place in an innovation process (**Fig. 1**):

I. the technological development of a sustainability-oriented innovation (technological level),

II. the organisation of network coordination for research and development (organisational level),
III. the governance of systems via policies that integrate sustainability-oriented criteria and indicators (governance level).

The technological level is represented by four case studies for sustainability-oriented innovations (EVI, ASTAF Pro, HayHeat, EiCare). The organisational level is represented by two case studies on research networks for transdisciplinary research (SENSOR IP, LIAISE NoE). The governance level is represented by one case study focusing on the policy assessment procedure for European Commission Impact Assessment (EU IA). The selection of case studies followed a deliberate search for activities in innovation support in the field of agriculture. A case study approach was applied to analyse the questions linked to innovation management for sustainable agro-ecosystems at each level of interaction.

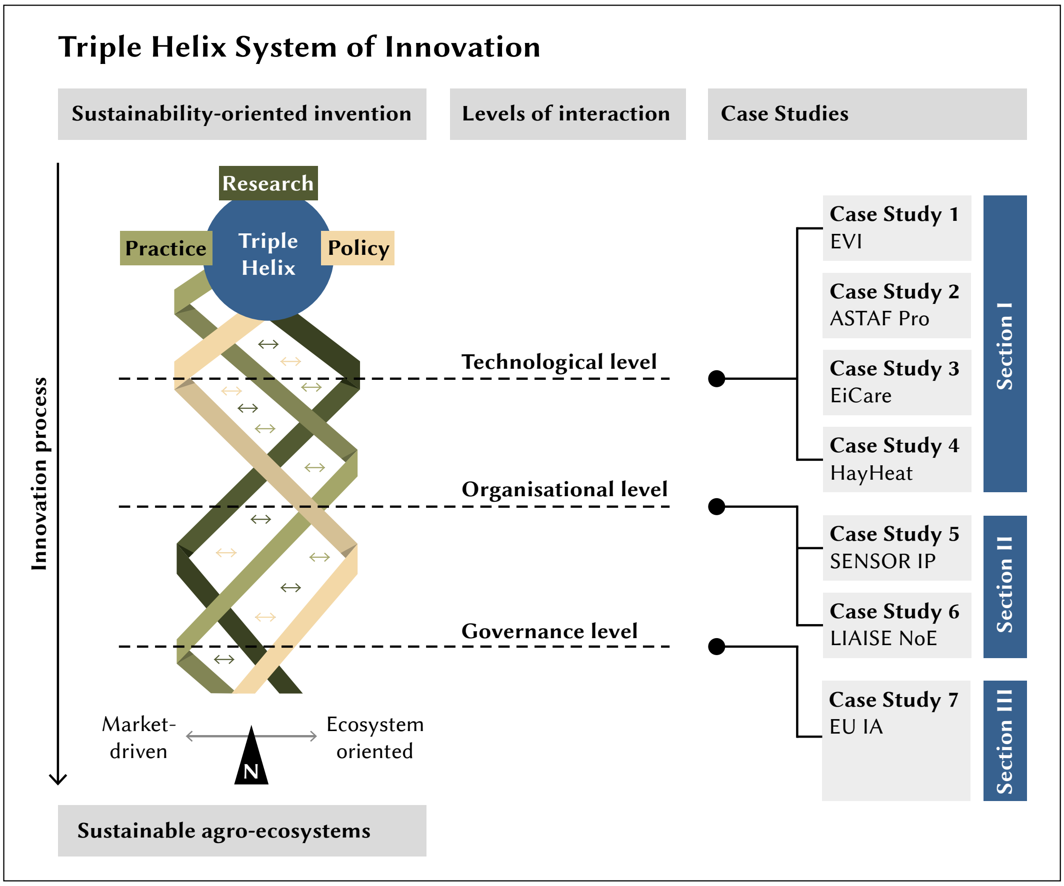

Fig. 1 The Triple Helix System of Innovation for Sustainability (THIS), developed by the author on the basis of Ranga and Etzkowitz (2013), specified and broadened for sustainability-oriented innovation processes, and applied to case studies in agriculture. Research questions relate to technological, organisational and governance aspects of relationship interaction in the innovation process, and the reconciliation between market-driven and sustainability-oriented activities at each level through negotiation (N).

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Results

SECTION I

Section I combines all case studies allocated to the technological level of an innovation process in the Triple Helix System of Innovation for Sustainability (THIS).

Transition to sustainable agro-ecosystems: steering sustainability at the front end of system innovations in agriculture

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ABSTRACT

With current farm management practices exceeding global natural resources capacities, there is an increasing societal interest in innovative approaches that support a transition to sustainable agro-ecosystems. Such initiatives involve system innovations that include changes in production processes, organisation and management alongside a technological innovation. An out-of-niche development of such innovations is challenged by high lock-in effects of existing value chains and limited knowledge of potentials and impact on the side of the actors involved in developing the innovation. The objective of this study was to apply a systems view of foresight in an early stage of innovation development. For this end, we deliberately selected four goal-oriented innovations in the German agricultural sector that were believed to support a transition to sustainable agro-ecosystems by the actors involved. For each case study, we analysed the front end of the strategic management process when competitive advantage and risk of failure were difficult to predict. We identified short term and long term goals relevant for the actors involved in each case and described the risks and potentials perceived in relation to sustainable agro-ecosystems. The results were structured into an assessment scheme to identify the coherence of the innovations with sustainable agro-ecosystems. Based on this investigation we discuss the characteristic features of innovations that contribute to the development of alternative farming practices and sustainable agricultural products. We further discuss where these characteristic features require additional engagement in the science-policy-practice-interface to initiate bi-directional knowledge transfer between the actors. We recommend the pursuit of designing transition-oriented innovation processes in research that can be applied in direct interaction with economically minded practitioners in the field.

Keywords: system innovation, foresight, land use, innovation system, impact assessment

1. Introduction

Agricultural strategies in the European Union articulate the belief that innovation has a major contribution to make in adapting land-use to the current interplay of market development, local natural-resource management and the political paradigms of sustainability, food security and climate change. Innovation for sustainable development has consequentially emerged as a high-priority topic in European Union in agricultural policy and research (EC 2016; EC 2011a). The agricultural sector in general, and particularly farmers, are confronted with an increasing expectation to adapt to global changes, ensure food security, limit environmental degradation and generate agricultural products that can compete in markets while supporting sustainable growth of rural territories (EC 2010). From the perspective of the farmers, the question is how sustainability goals can be approached through innovative changes that achieve a positive-sum game in economic terms.

A transition to sustainable agro-ecosystems requires continuous optimisation, technical advancement and redesign of farming systems (Tittonell et al. 2016; Tittonell 2014, Nicholls et al. 2016). Sustainable agro-ecosystems are considered particularly relevant in regions with a rich cultural landscape formed and influenced by decades of farming practice (e.g. Plummer et al. 2008). They make use of a per se natural environment to produce the maximum yield possible under the precondition of maintaining the natural resources the system depends upon. Their ecological properties support functional internal regulation mechanisms that require a minimum of artificial inputs from outside the system, and can recover from external disturbance (Gliessman 2001, p. 3). In terms of societal values, sustainable agro-ecosystems rely on local capacities to define, promote and reinforce subsidiarity as well as principles of civic economy. The concept is related to sustainable land management and multifunctional agriculture, and presumes co-production of public and private economic and social values (Di Iacovo et al. 2016; Manson et al. 2016; Stuiver 2006).

Implementation of goal-oriented innovation has a theoretical foundation in the fields of system dynamics (Geels 2004; Kropff et al. 2001), economics of innovation and technological change (Weitert 2014), and governance for sustainable development (Ashford & Hall 2011; Steurer and Trattnigg 2010; Newig et al. 2008). Changes in production, organisation and natural-resource allocation are regarded as system innovations that require a broad management process involving actors across different sectors and decision making levels to become effective (Elzen et al. 2004; Geels 2005). Model approaches, however, show that an out-of-niche development of such innovations is challenged by high lock-in effects of existing value chains and limited knowledge of potentials and impact on the side of the actors involved in developing the innovation (Manson et al. 2016; Nelson et al. 2014; EC 2011b; Guerin 2001). Previous research has dealt with two critical challenges: the increase of knowledge on environmental impacts, and the analysis of frame conditions for bringing innovative approaches into adoption and use. The former has brought forth an increasing range of integrated impact assessment tools that focus on stakeholder participation as well as credibility, salience and legitimacy of data used for decision-making in land-use related sectors to be used in the preliminary assessment of potential environmental impacts (Podhora et al. 2013; Jacob et al. 2013). Compared to earlier disciplinary approaches, these tools provide substantial improvement in the understanding of coupled human-environmental systems (Helming et al. 2012). The latter has been addressed by developing new mechanisms for supporting adoption and use through innovation management in business organisation. Instruments from business management include e.g. adaptive case management (Motahari-Nezhad H.R. 2013), or adaptive innovation management (Huber et al. 2016). Other, more land use related disciplines have come up with a range of frameworks, roadmaps and guiding principles for supporting technology development and knowledge transfer (e.g. Colloff et al. 2017; Schut et al. 2014; Fischer et al. 2012; Sheate & Partidário 2010; Blackstock et al. 2007). In these frameworks, researchers are given a key role as innovation brokers, mediators and co-developers that act in cooperation with stakeholders from production as well as marketing (Klerkx & Leeuwis 2008). Furthermore, current concepts consider land managers, policy makers and residents as influencers to the process who define the surrounding sphere in which an innovation can thrive (Läpple et al. 2016; Bouma et al. 2011; Chiva-Gomez 2004).

This study sets out to analyse the early planning stages of four cases of systemic innovations in agriculture that were believed to support a transition to sustainable agro-ecosystems by the actors involved. The aim is to assess the requirements for making a transition to sustainable agro-ecosystems operational through a management process that facilitates the development of innovations in agriculture. We address this by applying an expert-based foresight analysis to the front-end of a sustainability-oriented innovation development process. We thereby specifically address the following research questions:

a) what short term and long term goals are perceived relevant by the actors involved in the development of the innovation, and
b) what principles define the early integration of target knowledge into the design and management of a sustainability-oriented innovation process.

We thus contribute to the debate on sustainable innovation in agriculture by focusing on the front-end of systemic transition-oriented innovations based on agro-ecological principles in a multiple case study approach.

The front end of innovation in concepts of innovation management

The front end of innovation is a pre-development phase that takes place before a formalised management process is set-up to guide an innovation process. It is basically defined by the question, whether to invest resources in the development of a new idea (Mohan et al. 2017). Activities at the front end of innovation are described as holistic assessment approaches characterised by their highly explorative nature often driven by multiple actors and strategies (Hennala et al. 2016; Koen et al. 2001; Khurana & Rosenthal 1998). Given that innovative initiatives ever so often fail before reaching a market of users or consumers, the sound preparation of an innovation process may avoid later misalignment between strategies, unexpected lack of resources availability or counteractive target-setting. The purpose of activities at the front end is to prioritise next steps and development options by screening and repositioning the innovation in relation to known and assumed contextual factors, associated actors and resources. In management process models, the front end explicitly specifies a knowledge-intensive and weakly structured stage in an otherwise linear and structured process, e.g. Stage-Gate (Cooper and Kleinschmidt 1986), New Product Development (Ford et al. 2016; Jetter & Sperry 2009) and Business Model Innovation (Günzel & Holm 2013).

A classic front end process as described by Koen et al. (2001) involves five elements or activities that take place simultaneously in the process: opportunity identification, opportunity analysis, idea genesis, idea selection, and concept and technology development. The front end process is completed when an idea or invention can be articulated in form of a well-defined concept or roadmap that includes timely and specific goals, and ideally attains investment and resources for further development. The combination of action-oriented activities such as idea generation and concept development next to assessment-oriented activities such as analysis and selection adds to the non-linear and unstructured nature of the process.

The particular vagueness in innovation development stages associated with the front end is recognised both in concepts related to the Innovations Systems Framework as well as in linear process developments such as the Stage-Gate Process. Although more prominently associated with linear concepts, where front end innovation is understood as a defined and temporary phase that takes place before later stages of development and market entry (e.g. Cooper et al. 2002), innovation system concepts likewise highlight this phase as the invention phase, albeit linking it also to later stages of development (e.g. Anadon et al. 2014). We exemplify the main differences in the reception of the front end by comparing its role and rationale in **Table 1**, beginning with a Stage-Gate Process and proceeding with a framework from Innovation Systems. The third column shows how the front end relates to the Systemic Foresight Process applied in this study.

Table 1 Comparison of the front end of innovation in a linear stage-gate process and an innovation system framework from a management perspective.

	Stage-Gate Process	Innovation System Framework	Systemic Foresight Process
Description	Managing a structured time schedule of linear events in an innovation system	Understanding and evaluating relevance and hierarchic structure in an innovation system	Application of a hierarchic system onto a time schedule for future innovation development
Rationale	Quantitative analysis of success in the innovation processes	Qualitative analysis of functions in an innovation process of system dynamics	Analysis based on case studies and comparison
Objective	Economic success under consideration of contextual factors (e.g. socio-technical)	Categorisation of success factors (e.g. economic, socio-cultural, socio-technical)	Integration of short term and long term goals (e.g. economic, social and environmental)
Choice of methods	Subject to types of innovation and their development stage	Subject to interrelations between actors and objects in the innovation system	Subject to interrelations between actors and objects at each development stage
Strategic focus	5-8 gates in a unidirectional process	6 stocks and 7 flows in a multi-dimensional hierarchic space	Multi-dimensional hierarchic space per stage
Structure	Formalised linear process with stages and gates	Model of stocks and flows in hierarchic levels	Deduction of hierarchic stocks and flows formulated for each stage and gate
Function of the front end	Explicit temporary phase before the actual innovation process	Implicit part of activities embedded in the innovation process	Current position looked upon from an anticipated future
	Selection of promising ideas and inventions according to product profitability and financial risk	Evaluation of risks and potentials according to costs and benefits, enabling and inhibiting factors	Priorisation of objects and goals according to actors requirements
References	Cooper 2014; Koen et al. 2014; Cooper 2008; Cooper et al. 2002; Koen et al. 2002	Anadon et al. 2014, Harley et al. 2015	Dufva & Ahlqvist 2015, Georghiu & Keenan 2008

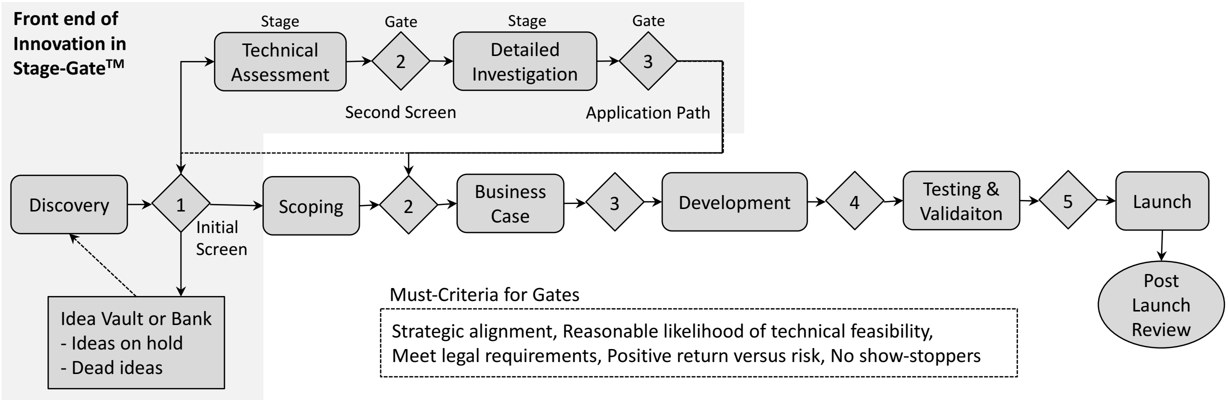

Fig. 1 The front end of innovation highlighted in a logic model of a Stage-Gate Process (adapted from Cooper et al. 2002).

Planning management processes with a system view

Front end innovation in stage-gate processes

The Stage-Gate™ was developed by the Product Development Institute Inc. from earlier models of phased review processes in project planning (used e.g. by NASA) and based on evidence of key activities that positively influence the success rates of innovations (Cooper and Kleinschmidt 1986, Cooper et al. 2002). It was initially focused on guiding product innovations through scoping, development and testing. It applies a standardised protocol of alternating expert-based group-learning phases of assessment ("stages") and stop/go-decisions executed by the management level ("gates") along a set of criteria (**Fig. 1**).

Gradually, it became a more adaptive stage-gate system that now explicates iterative loops in each stage, parallel cross-functional activities ("fuzzy gates") and spiral developments leading from the building of knowledge over testing feasibility, testing practicality to proving profitability and managing the life-cycle. A discovery stage was added up to the process to facilitate an initial screening of ideas. Furthermore, the stage-gate process was adapted to technology development processes where the immediate deliverable is not a new product but a new knowledge or capability that may eventually lead to new products. This added two additional stages to the front of the process, mainly aimed at harnessing "undirected, unfocused and unproductive" fundamental research by stages of technical assessment and detailed investigation. Key activities across all stages are context mapping, experiments, scenario development and cross-functional expert-based opportunity and risk assessment (Cooper et al. 2002; Cooper 2014).

Front end innovation in innovation systems research

A framework for technological innovations based on system dynamics (Bergek et al. 2008) and innovation systems (Pavitt 1984; Lundvall 1992; Malerba 2002) was set up by the Sustainability Science Program at Harvard University, Cambridge (Anadon et al. 2014) (**Fig. 2**). This framework describes the innovation process as a "flow" of technol-

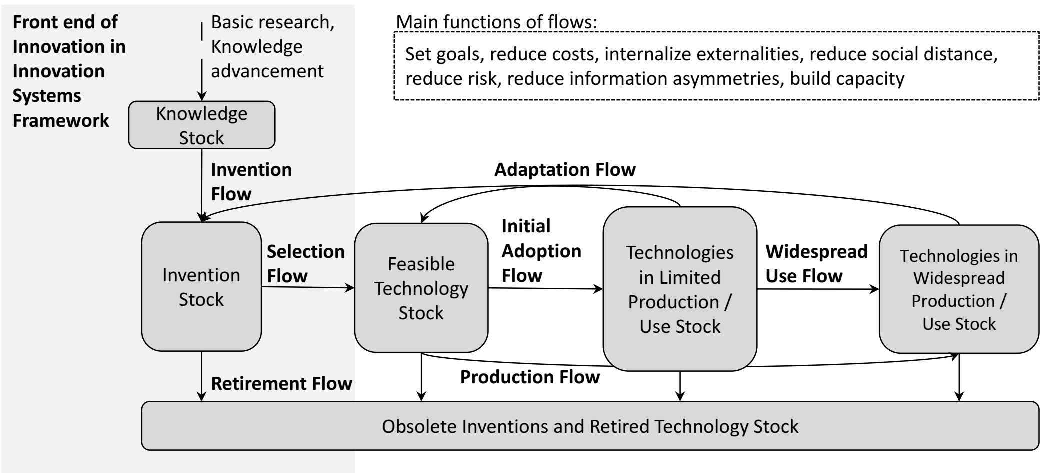

Fig. 2 The front end of innovation highlighted in a flow model of an innovation systems framework (adapted from Anadon et al. 2014).

ogy between "stocks" at different stages of development. Stocks are tangible and countable. They are determined by the technology itself and its context, mediated by actors and socio-technical conditions. The main emphasis is on the non-linear flows which have key functions across the whole process. Each flow starting from a stock comprises a different set of mechanisms that work towards the next stock. The early development stages are characterised by invention mechanisms such as goal-oriented search, experimentation and repurposing starting at the knowledge stock, and selection mechanisms for evaluation and selection by users, policy makers and agents starting from the invention stock. Key activities across all flows are management oriented and include diagnosis of enabling and inhibiting factors, evaluation of context factors, identification of actors and institutions, selection and allocation of functional mechanisms and actions, identification and allocation of resources.

Methodological framework for a systemic foresight process

Foresight processes link between linear and systems thinking in transition processes by convening a system view on a practical problem of decision making (Dufva & Ahlqvist 2015). Foresight is based on the assumption that the future can be shaped in positive ways by an improved understanding of options and risks, driving forces and underlying processes of change. By applying a set of formal translational activities that involve scientific as well as non-scientific experts with different backgrounds and perspectives via participation, the perspectives of agents are brought into a larger process of change (Miles et al. 2008, p. 14). This can eventually lead to changes in cognitive schemes of the agents and therefore give a novel interpretation to the discussion around exploration and exploitation.

A reflexive element in foresight can be included into the foresight process by including back-casting as one of the set of methods applied (Popper 2008, p. 55). A back-casting viewpoint is taken, where at the time of planning future scenarios are envisioned and impacts illustrated in order to provide choice options for planning. Facts and figures on the one hand and normative judgements on the other enter the decision-making process in form of a structured dialogue that is perceived to be, ultimately, a learning process. Prospective impact assessment and target knowledge can thus be included in the planning phase to improve the design and decision-making of the management process by providing, weighing and modulating choices between different options across sectors over time (Dunlop & Radaelli 2015).

With the intention to cover the front end of innovation, we propose a methodological approach based on three basic scoping elements suggested by Popper (2008, p. 45) and further developed by the authors (**Fig. 3**):

Step 1: Assemblage of the foresight team

The foresight team is determined by the function of the actors in relation to the innovation. The selection is based on the actors' personal investment, involvement and concern in the development of the innovation. Following this functional approach, we consider three basic groups in the

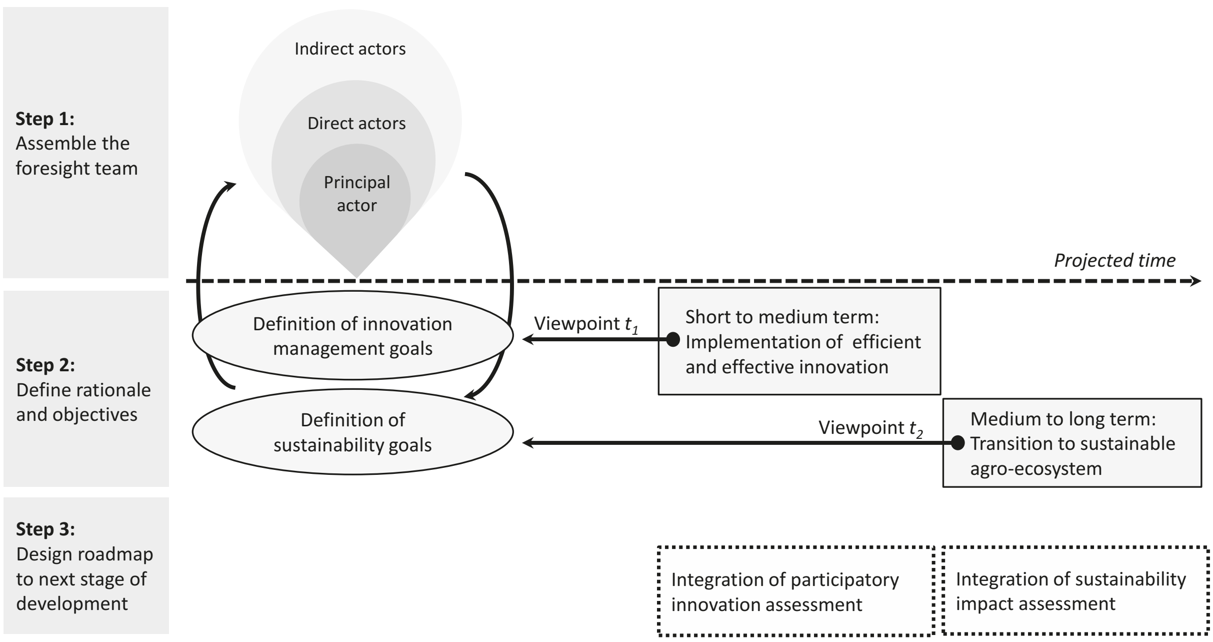

Fig. 3 Integration of target knowledge in a foresight process for front end innovation assessment using back-casting (authors own compilation). Viewpoints $\mathbf{t_1}$ and $\mathbf{t_2}$ describe the user perspective taken from the final stage of the process.

foresight team: 1) Inventors and champion promoters of an innovation (**principal actors**) who are considered key carriers of knowledge regarding the historic development of the innovation, the production process development, and the systemic problem that is targeted; 2) Implementers and managers of the innovation (**direct actors**) who as a group are knowledgeable of technical and developmental aspects as well as potential risks linked to the innovation; and 3) People affected by the innovation in a positive or negative way (**indirect actors**). The latter involve in the foresight process from a perspective of affectedness, thereby contributing to an early mitigation of negative impacts.

Step 2: Define rational and objectives

Rationale and motivations are clarified by establishing a joint knowledge base between the actors. The innovative aspects are made explicit, while objectives are identified and discussed. This step contains a continuous reference back to the requirements articulated by the actors in the foresight team. We distinguish two types of objectives to be addressed in the process: 1) **innovation management goals**, and 2) **sustainability goals**. The innovation management goals relate to the invention and its development into new products and services embedded in a market environment. Sustainability goals relate to the function of the invention within the wider context of the sector and region, and eventually the transition to sustainable agro-ecosystems. The back-casting exercise takes account of this differentiation by taking a short-term viewpoint for identifying innovation management goals, and a long-term viewpoint for the sustainability goals.

Step 3: Design methodology of the foresight process

Lastly, the systemic foresight process is designed based on methods suit the context and need of the actors. The implementation of the foresight process is conducted as part of an inter- and transdisciplinary project approach leaning on methods of participatory research, action research and sustainability assessment, whereby network analysis, situation analysis, expert interviews and focus group workshops are applied (König et al. 2013). The focus group workshops are steered by an external moderator. The process is underpinned by regular meetings for scientific reflection, thereby allowing the main actors to participate in the design of the assessment framework. The workshops aim at setting up a roadmap that provides actor-based information for all the relevant elements of front end assessment described by Koen et al. (2001): a) supports opportunity identification and idea genesis by bringing together a diverse range of actor perspectives, b) back the assessment of opportunities and selection ideas through an identification and clarification of innovation management goals, and c) assist the specification of concept and technology development by considering sustainability goals.

3. Methods

Selection of case studies

Four case studies were selected upon a deliberate search for innovative approaches that were being developed in the agricultural sector in north-eastern Germany. The selection was determined by the innovations potential for supporting a transition to sustainable agro-ecosystems, as perceived by the actors involved. Furthermore, the selection was determined by the need for a front end process, indicated by an unspecified need for additional (experimental) research and product trials, consultative monitoring, funding, investor-relationships and expertise. All case studies were found to represent the typical initial complexity of a systemic innovation process in agriculture, with particular difficulties in establishing the innovation as an alternative to existing production and value chains, and in reaching competitive economic scale. The case studies were finally selected because of the relevance of the problem they addressed. In all selected case studies, the targeted problems were understood to be relevant to a niche sector, but were likely to become increasingly relevant under on-going global changes, such as climate change, food security or migration to urban areas.

1) **EVI**: a biological control agent for soil-borne pathogen regulation (2009–2014);
2) **ASTAF Pro**: a double recirculation system for aquaponic systems (2009–2014);
3) **EiCare**: the re-introduction of dual-purpose poultry production systems (2014–2019);
4) **HayHeat**: a small-scale thermal production from biomass in marginal grassland (2014–2019).

Overall case study approach

The case studies were analysed for approximately five years in the frame of third-party funded projects financed by national ministries in order to improve innovation processes in agriculture. In each case, the foresight process took place within the first year of the project. The results were used to inform the project team, and to set up a roadmap for the organisation and management of the innovation process. At the outset, each case study was found at a different state of development. Also, the objectives differed (**Table 2**). The objectives were treated as equal and non-hierarchical in the sequence of activities. The focus was determined by the project team together with the main actors in the innovation system. In two cases, the initiative was driven by researchers, while two cases were driven by practice, with actors positioned in the management of a biosphere reserve and a marketing organization.

Table 2 Overview of case study settings.

Case study	Principal actor	Direct actors	Indirect actors	Interviews
1. **EVI**	Leibniz-Centre for Agricultural Landscape Research (ZALF)	Farmers with a history of strawberry production and field disease infestation in Brandenburg; Manufacturer of biological soil conditioners	Authorities for crop protection Extension services Consultancies Strawberry breeders	13
2. **ASTAF Pro**	Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB)	Researchers involved in the invention and implementation of the aquaponic system	Aquaculture production Vegetable production Greenhouse engineering and design	11
3. **EiCare**	Naturland Marketing GmbH	Farmers with total poultry production of 3000 hens produced and marketed in cooperation with Naturland	Processors (meat) Extension services Breeders Marketing organisations	13
4. **HayHeat**	UNESCO Biosphere Reserve Spree Woods, State Office for Environment	Smallholder farmers with joint land ownership of 1000 ha in the Spree Woods/Błota	Tourism Nature conservation Hunters and fishermen	15

Design and implementation of the foresight process

Step 1: Identification and assemblage of actors

The identification of actors started with a preliminary internet search and was followed up using the snowball principle. A total of 52 guided expert interviews were conducted to identify the specific concernment of the actors as well as their interest and expectation towards the innovation. The interviews sought to identify the relationships, motivations and functions of actors in regard to the innovation. Furthermore, they were used to identify further the potential opportunities and risks perceived by the individual actors (**Table 3**). The interviews were transcribed and used as a database in the subsequent foresight process.

Step 2: Definition of rationale and objectives

The transcribed interviews were used to assess in more detail the state of development at the outset of the innovation process, and to identify the objectives related to the short- and long-term.

Table 3 Actors involved in the innovation case study research.

Case Study	Promotion of initiative	Orientation of Intervention	State of development at the outset	Objective
1. **EVI**	Science driven	Spatial (Wilt infested fields in Brandenburg)	Patented technology based on agro-ecological principles	Feasibility in agricultural practice
2. **ASTAF Pro**	Science driven	Sector (Horticulture and Aquaculture)	Patented technology and concept for a model of multi-functional agriculture	Cost- and resources efficiency
3. **EiCare**	Practice driven	Sector (Poultry)	Limited adoption of a model for multi-functional agriculture	Scalability and out-of-niche development
4. **HayHeat**	Practice driven	Spatial (Biosphere Reserve Spreewald)	Feasible technology and concept for multifunctional agriculture	Proof-of-concept and implementation by first adopter

Short-term goals mainly addressed administration, organisation and planning of the development process. The time frame generally covered a prospective two to five years. In principal, the short-term goals were related to the achievement of an efficient and effective model for agricultural production, and thus focused on the management of the innovation towards adoption by consumers and users.

Long-term goals addressed the focus and alignment of the development process to principles of sustainability. The time frame for achieving goals was seen in an indeterminate future. Long-term goals were in principal related to the achievement of a transition to sustainable agro-ecosystems, and thus focused on aspects of achieving sustainable development within the region or sector addressed.

Step 3: Design roadmap to next stage of development

Based on the analysis of the interviews, an initial screening of the innovation was conducted in preparation of back-casting exercise (**Table 5**). Two aspects were looked at: the potential of the innovation (innovation potential), and the potential of the innovation to contribute to sustainability (sustainability potential). The screening was based on the expertise of the researchers from extensive communication with the principal actors as well as topic-related scientific literature and external expertise. A roadmap is designed under consideration of the target-knowledge collated, thereby bringing together aspects of impact evaluation as well as management.

5. Results

In the following, we summarise the results from applying the foresight assessment.

1) Biological control agent for soil-borne pathogen regulation (EVI)

Inoculation of plants with non-pathogenic strains of microbiologic organisms as a biologic control agent has a potential for being applied as a management measure in integrated pest management. The concept is based on the observation that preoccupation of an ecologic niche will render plants immune to infection. The inoculation of strawberry plants with soil-borne non-pathogenic *Verticillium* strains was developed upon developing a suitable method for an isolation of strains. The biologic control agent was tested under laboratory conditions for the strawberry cultivar 'Elsanta', and filed for patenting (Lentzsch et al. 2007; Schubert et al. 2009). The application of a biological control agent involves **a system shift**

Table 4 Innovation management goals (short term) and sustainability goals (long-term).

Case Study	Short-term goals	Long-term goals
1. **EVI**	Develop a viable substrate for field application. Test the technology in cooperation with farmers. Assess efficiency and effectiveness in commercial strawberry production.	Transfer of technology to commercial strawberry production. Improve viability of strawberry production in production sites with high risk of *Verticillium* infestation.
2. **ASTAF Pro**	Identify suitable first adopters. Assess suitable sector niche and product vision for commercial business case development. Develop setting for proof-of concept for feasibility and commercial viability of the concept.	Organic and local production of vegetables and fish in specific local settings (e.g. urban, arid, dense settlement areas). Improve local supply of vegetable and fish produce.
3. **EiCare**	Raise efficiency of production and marketing in extensive poultry production. Assess potential for widespread adoption of the model.	Ethical and organic production of poultry in small-scale production units. Raise supply of organic meat and eggs for local distribution of whole chicken and eggs.
4. **HayHeat**	Test feasible technology in specific setting of biosphere reserve. Identify and set up farmers' cooperative that adopts the concept via pooling of fields. Assess benefits for nature conservation and regional sustainable development.	Use of surplus biomass for local production for the benefit of biodiversity in marginal wetlands. Improve income situation for small scale farmers with production sites in marginal wetland areas.

Table 5 Estimated potential of the case study innovations.

Initial Scoring	EVI	ASTAF Pro	EiCare	Hayheat
Innovation Potential				
Complexity of the innovation	⇨	⬀	⬂	⇧
Development costs	⇨	⇧	⬂	⇧
Adoption costs	⬂	⬀	⇨	⇨
Practical fit to production process	⬀	⇨	⬀	⇧
Feasibility in local setting	⬀	⇨	⬀	⬀
Sustainability Potential				
Market entry threshold	⇨	⇨	⬂	⇧
Research and development requirements	⬂	⬀	⬂	⇧
Nature conservation potential	⇧	⬀	⇨	⇨

within the production process from treatment after diagnosis to prophylactic treatment.

Wilt disease caused by *Verticillium* was considered one relevant challenge in strawberry production next to other problems such as price competition, climate and irrigation. In Brandenburg, loss of production due to wilt was assessed between 5 and 50 % depending on location and cultivar, whereby cultivars with positive features for marketing and transport were particularly sensitive towards wilt. The development of the biological control agent was promising due to an absence of other measures for regulation since the phase out of chemical biocide usage (EU regulation No. 528/2012).

The inoculation of the plant could in principle be conducted at different steps of the production chain, either within the nursery, during preparation for sales and trade or directly before planting. However, questions of liability and quality certification suggested treatment by the farmer before planting. In terms of product development, farmers favoured a fluid that could be applied by dipping plants, as an alternative to solid products based on straw or soil substrate.

Mainly small farms were affected by *Verticillium* wilt. Due to a general lack in risk capital available for small farms, no farmer could afford innovation development as an individual. However, non-farm investors required further proof-of-concept in production site field trials as well as economic scope. Further research was required also for soil diagnosis to improve the efficiency of the application.

Short-term goals: Farmers required a technically viable solution to improve the overall viability of strawberry production in production sites with a high risk of *Verticillium* infestation. Plant nurseries and traders aimed at safeguarding the production chain and hedging their financial risks in terms of guarantees for trading healthy plants.

Long-term goals: Farmers aimed at maintaining the areas for fruit production in the region and by increasing the ability to deliver sufficient quality and quantity to meet the demand for locally produced fruit. Representatives of the policy sector aimed at improving the situation of fruit and vegetable farming in the region to maintain traditional farming areas and cultural landscapes, and also ensure production capacities in face of a growing demand for regional food products.

Innovation potential: Propensity to invest in biological control agents was estimated at 1000 € per ha per year by farmers who experienced 20 % yield loss or more due to wilt. The benefits were seen in biennial crop cultivation and stabilisation of higher yields. Developed as an aqueous suspension, the shelf life was expected to cover a minimum of 4 weeks to bridge transport, trade and storage before application. The application of the suspension should be adaptable to the planting procedure. Generally, the plants are root-dipped for ca. 10 min before planting at 3–4°C outdoor temperature. Technical production of a suspension was estimated as feasible within 3–4 weeks.

Sustainability potential: Brandenburg has ca. 400 ha of strawberry production. Yields are lower as compared to other regions due to cultivation practices, poor soils and climate conditions. However, production adds to the local income and job situation in the region. An increase of market potential is limited due to price competition with imported fruit. Many farmers follow a strategy of direct marketing at farm gate. A biological control agent was expected to stabilise yields and income. Further market potential was found to depend on the suitability of the product to other cultivation practices and climatic regions. Furthermore, a demand is created in all countries with strict regulations for chemical biocides. An application was considered viable in Germany, Spain, Sweden, Austria, Poland and Croatia, covering an estimated 37.000 ha. Main concerns in terms of sustainable application were the genetic stability of the biological control agent, its effectiveness (lasting impact), and potential stress reactions in the plant. Furthermore, a safe application of micro-organisms to soils was considered a prerequisite out of environmental concerns.

Outcome: The results were translated into an experimental research design for the optimisation of the biological control agent. This was followed up by conducting two-years of field trials under commercial conditions in Brandenburg (Diehl et al. 2013). The field trials showed negative results due to an unexpected infestation by other pathogens. An improvement of the biological control agent through combination with other measures for pesticide control would have required further funding.

2) Double recirculating system for aquaponic systems (ASTAF Pro)

The coupling of an aquaculture system with a hydroponics unit is challenged by the different requirements for optimal production in each system. The development of a connecting valve allowed a new layout of the water cycle resulting in a double recirculation system. The system was tested for tilapia fish (*Oreochromis niloticus*) and tomato plants under laboratory conditions, and was found to considerably improve the efficiency of water and nutrient recycling in greenhouse production (Rennert 1992). A patent was filed (Kloas et al. 2008). The implementation of the system involves the **merge of two independent production sectors**, namely aquaculture and vegetable production.

An upgrade of an existing system by adding the complementary unit (e.g. a vegetable producer adding a fish production unit) was mainly challenged by a lack of expertise in the respective other system. An implementation was considered highly knowledge intensive, requiring input from research, greenhouse manufacturing, organisation and management. While an upgrade of an existing system was considered too costly overall, an implementation of the concept through a novel series of aquaponic greenhouses would require considerable investment into a merging of production organisation as well as supply and marketing logistics.

Short-term goals: Farmers required a test-case exhibiting the benefits and production output figures as well as the viability of the concept for commercial business development.

Long-term goals: Farmers aimed to increase the local supply of vegetables and fish produce to meet the rising demand for organic and local production in specific local settings (e.g. urban, arid, dense settlement areas). Farmers also wished to adapt greenhouse systems to systems of alternative energy production.

Innovation potential: Production of vegetables and fish in greenhouses is knowledge intensive and requires substantial financial capital. Economic efficiency mainly depends on energy prices that make up ca. 30–40 % of costs. Relative benefits due to water efficiency are not a determining factor under current water prices. The system should be available as a modular system that can be integrated into horticulture production, aquaculture production and energy production systems at different scales. The complexity of upgrading existing systems suggests that integration must take place at the planning stage, thus involving the manufacturers of greenhouse systems.

Sustainability potential: The relative benefit of merging two previously unrelated production sectors led to two product visions with an expected effect on sustainable food production. The first product vision was a niche market option for the production of certified organic vegetables and fish in an urban environment, eventually leading to new jobs, e.g. in food catering. Potential markets were seen in countries with a market for high-priced food products, such as Central Europe, USA and Japan. This option would solve the limited nutrient availability in organic food production, and have a positive impact on the spread of disease due to the closed production system. The main potential partners for further developing this option were producers of vegetable and fish. The second product vision involved the production of vegetables and fish in arid or contaminated areas, such as Central Asia, Northern Africa, Middle East, Mediterranean, China and Japan. This option would require substantial development in engineering and construction of greenhouses. It would address production under limited resources, and have a positive impact on food security and emission reduction. Market potential in both product visions was based on further development of decentralized agricultural production in rural and urban settings, policies for resources-friendly food production and eco-efficiency. Cutting down the use of natural fish stocks, and the reduction of emissions compared to existing greenhouse systems could eventually lead to positive environmental impacts.

Outcome: The results pushed further experimental research to improve the data availability on production output, efficiency and investment costs, as well as relative economic and environmental benefits (Kloas et al. 2015). Furthermore, the assessment was followed up by an extensive sustainability assessment with the aim to detect open research questions for further improvement (König et al. 2016).

3) Dual purpose poultry production systems (EiCare)

In poultry production, an increase of large-scale production entities based on economies of scale has led to highly specialised systems of meat and egg production. Dual purpose production systems build on the concept of an ethical and organic production of layers and broilers simultaneously in small herds, with a focus on local distribution as well as quality-oriented marketing. The innovative approach involved the creation of a brand for marketing ethical production and conservation of breed diversity. The test phase of the concept was implemented by six producers in Brandenburg and Mecklenburg-Vorpommern starting in 2014, and is on-going. The brand was protected under the label of EiCare by Naturland Marketing. An implementation of the concept requires **a shift in production and marketing including a reorganisation of supply chains**.

Organic poultry production in Germany had a market share of ca. 9 % in 2013 with rising figures of 13 % in meat production and 16 % in egg production (van der Linde et al. 2014). Organic producers have in recent years invested in furthering production optimisation and alternative approaches, such as mobile henhouses or dual purpose and low input breeds (Leenstra et al. 2012, Brade 2008). The proposed approach sparked the interest of producers, who were motivated to support organic and ethical production. On the consumer side the market has not been developed in the same speed. Consumers are confronted with considerably higher prices due to difficulties in market entry and development of alternative value chains.

Dual purpose poultry production is mainly challenged by not achieving economies of scale. In consequence, the development focus is put on increasing production by transferring the concept to further production sites. Other challenges involve the establishment of a market for ethical and organic produce. The success of the innovative approach was found to rely on improved vertical integration along the value chain, particularly of producers, traders and shopkeepers as well as actors from the marketing organization. The main challenge in terms of distribution was seen in the regulation of supply and demand as well as better sales and marketing channels. The practical focus of farmers was related to a lack of benchmark figures in production, but also to a void in supply chain infrastructure for alternative production processes.

Short-term goals: The farmers as well as the marketing organisation aimed to increase the efficiency of production and marketing. Farmers also required technical support in farm management to solve shortfalls in production due spread of disease, lack of modern technical equipment or insufficient infrastructure in buildings and transport. The marketing organisation required more efficient distribution channels and the development of regular and continuous supplies.

Long-term goals: The marketing organisation aimed at widespread adoption of the model to support small scale farming and ethical organic poultry production to raise the supply of organic meat and eggs. Farmers aimed for a stable income situation and a functioning supply chain for optimising production output, all in all leading a higher representation of small scale poultry production within the sector.

Innovation potential: Meat and egg products must meet the quality standards of consumers willing to pay for high-priced food products. An implementation of the system depends on the knowledge and expertise of the farmers as well as some flexibility and ability of the farm to adapt to unconventional supply chains. The approach is suitable for areas logistically connected with the urban market environment where the consumer segment for high-priced food products is large enough. Cost-efficiency must reach a level, where it can compare to other organic poultry production systems.

Sustainability potential: Dual purpose poultry production competes not only with highly specialised production, but also highly specialised marketing. Supply chains have developed in entirely separated lines for egg and meat production, and marketing channels have developed for different parts of the chicken on a global scale. The market potential of dual purpose production depends on a rising societal awareness for resources-friendly, organic and ethical food production where the whole chicken is marketed in a regional environment of ca. 200 km from the production site. Out-of-niche development was found to rely on an optimisation of the concept to further increase productivity a well as market development, particularly for meat products. Positive environmental impacts can be achieved by the ability of the approach to minimise food waste, to reduce transport emissions due to local and regional supply chains (e.g. by reducing feed imports), and to reduce global impact of trade due the use of local marketing channels.

Outlook: The results were followed up by developing management tools for an improved organisation of production under consideration of the whole supply chain. The aim was to overcome market entry barriers. Different marketing approaches were tested, with activities still on-going in 2017.

4) Small-scale thermal production in marginal wet grasslands (HayHeat)

Marginal wet grasslands require site adequate management practices to achieve yield. This has led to characteristic and highly biodiverse open landscapes over time. However, previous usages of grassland biomass, for example as dry litter in barns for beef production, have phased out. In the absence of profitable utilisation strategies for surplus biomass under current farming conditions (intensification on the one side and land abandonment on the other), the maintenance of cultural landscapes requires new forms of management based on concepts of "conservation through utilization". A decentralized straw combustion plant for thermal energy production was developed for the use of surplus biomass from 2.000 ha of marginal wetland located in the Man and Biosphere Reserve Spreewald in Brandenburg. Developed from technology available for wood combustion by Herlt GmbH, a prototype was installed by one farmer in 2016. The installation was endorsed by the management of the biosphere reserve for its potentials in benefitting biodiversity conservation as well as maintaining the cultural landscape for the local nature tourism sector. The concept thus foresees an involvement of 30 additional small-scale farmers who provide biomass as well as 5–10 tourism providers who adopt the technology and communicate the concept. Thus, an achievement of public and private economic and social values in the Spreewald region through an implementation of the concept requires the **reorganization of capacities through merging of supply and value chains across sectors**, namely agriculture and tourism.

Short-term goals: The aim of the biosphere reserve management was to prove efficiency and effectiveness of the concept of thermal energy production in one case, and to communicate the concept within the group of owners of marginal grassland in the biosphere reserve. The aim of the first adopter was to optimise the technical operation of the plant for private use and regional upscale.

Long-term goals: The main aim of the biosphere reserve management was to maintain open landscapes for nature conservation and regional nature tourism. Farmers and land owners aimed at implementing a viable solution for retaining ownership and use of marginal wetland sites based on extensive farming.

Innovation potential: Based on previous experimental operation of the plant, the expected energy output from biomass harvested from 1 ha equals the heating of one single-family home. The combustion plant sparked interest in farmers and land owners who strongly identify with the natural assets of the Spreewald region, but also in local entrepreneurs in tourism who seek a unique selling proposition for the region. The straw combustion plant for thermal energy must be available at different scales from one single-family house to hotels and more complex building structures. An implementation of the system depends on the capacity of farmers to invest in modern energy infrastructure, and their willingness to invest in environmentally-friendly alternatives to fuel oil. The approach is suitable for areas with patchwork farm structures and well-organised land owners. It depends on the ability of regional land managers to communicate the benefits of the combustion plant and acquire funds for initial investment.

Sustainability potential: Valorisation strategies for cultural landscapes are often linked to state supported nature conservation sites. The local production of ecosystem services is expected to provide a basis for small-scale nature tourism and entrepreneurship in rural environments. UNESCO Biosphere Reserves commit to explore models for environmentally friendly regional economic development in their management plans. The Biosphere Reserve Spreewald has a total area of 470 km^2, with ca. 2.500 ha of marginal wetland with a high value for biodiversity. Maintenance of wetlands was largely linked to state subsidies which were considerably reduced in recent years under European regulations. Further market potential depends on the ability of the innovation to compete with state subsidies. Before 2010, ca. 0,47 Mio € subsidies were paid to 135 farm enterprises in the biosphere reserve. In combination with other programs for extensive agriculture, an average subsidy of 285 € per ha could be expected by the land owners and farmers. The valorization of the biomass potential relies on the pooling of fields that exist in a typical patchwork structure of fields ranging from 0,5 to 3 ha per unit. A positive environmental benefit can be achieved by providing thermal energy at an optimised scale. Ultimately, the benefit is seen in the conservation of biodiversity, particularly marginal wetland habitats with their characteristic species endowment.

Outcome: A development of the straw combustion plant for thermal energy production from surplus biomass requires an upscale in plant construction and mechanical engineering. Implementation of several plants for achieving the expected impact requires horizontal organisation between land owners and the biosphere reserve management as well as vertical organisation from the farmers to the tourism sector (König 2016). Experimental operation of the straw combustion plant was still on-going in 2017.

6. Discussion

The result of the foresight assessment applied to the front end of innovation is a highly qualitative, strategic and management oriented assessment used for decision support in planning an innovation process. It is experienced as time-consuming and knowledge-intensive, requiring iterations in communication within the project team and feedback loops with external experts. In the following we discuss the specific nature of the innovations that were expected to contribute to a transition to sustainable agro-ecosystems. We highlight four distinct characteristics leading to higher complexity and discuss actions that could contribute to an improvement of the innovation process.

Application of the foresight process

The approach used in this study is value-oriented. The assessment criteria and methods were developed in cooperation with the actors involved in the innovation system. Adjustments were made to accommodate for flexibility over time. The result is an iterative "learning assessment", where the actors first articulate what they perceive as relevant and later check their activities against their own set of values.

Ultimately, all case studies in this research propose an innovation towards a systemic shift. While a business proposal has to pass against market requirements, the innovative approaches presented here additionally have to pass against societal values. However, neither of the actors can have full knowledge of the whole system and its internal and external influencing factors. Stage-gate processes generally assume a company or firm with a middle management that takes decisions to develop an innovation (Cooper 2008). In the innovation systems framework, intermediaries take over this role (Klerkx & Leeuwis 2009; Klerkx & Leeuwis 2008). Intermediaries are individuals or organisations that are knowledgeable of the issue but stand outside the immediate network of actors involved with developing the innovation.

The benefit of the structured process in systemic foresight is that it creates a "virtual third party" by bringing together all relevant perspectives that stand representative for society. Thus, the innovation is assessed against the societal values by the involvement of a small subset of actors. The representation of actors in this group is crucial, and requires careful pre-assessment (for an overview of methods see e.g. Colvin et al. 2016; Reed et al. 2009). Furthermore, a trade-off can be expected between having an open process on the one side, and a closed niche for development on the other. Innovations are generally sensitive to openness. The foresight process has to maintain a certain closure to maintain an incubator function of the process.

The second benefit of the process is that it allows for the internalization of externalities at a very early development stage. The integration of target-knowledge helped to develop a niche that fosters an innovation culture and encourages decision-making comprehensiveness (Mohan et al. 2017). In order to reach the goal, the essential features of sustainability need to be integrated at the very beginning of the development of an innovation. An integration of sustainability requirements at the front end thus becomes relevant for planning the roadmap. While typical questions in the planning stage include "what is there?", "what is new?", "what is attractive for consumers?", "what works?" additional questions now address issues such as "**what are positive environmental effects?**", and "**how will they be accounted for?**"

The front end of innovation implies that this development phase of the innovation process is somewhat "mysterious" (Koen et al. 2001, p. 46), and this attitude often results in a lack of accountability and difficulty in determining who is responsible to manage activities in this phase. The implementation of the management plans that resulted from the foresight process in all four case studies fell within the responsibility of the principal actor. This is in accordance with innovation management experience in so far as the innovation needs to have reached a certain stage of development to attract third parties. This result also indicates that the front end approach was adequate in all four case studies.

Characteristic features of innovations supporting transition

Innovations that are expected to contribute to a transition to sustainable agro-ecosystems involve an intervention in the ecological system, often at more than one single interface. In the case of EVI, for example, the microbiological system is influenced by the biological control agent, but also the selection of plant material, the process of planting and harvesting will have an impact on the interactions between soil and plant. Lastly the maintenance of strawberry farms as part of the cultural landscape will influence the ecological system at landscape level. The capacity for ecological intervention sets the case study innovations apart from the definition of innovations offered by OECD (2005, p. 47) which describes technological change in terms of product innovation, process innovation, marketing innovation or organisational innovation. All four categories described by OECD are manifestations of different aspects of the same technological change within one innovation system. Geels (2005) defines a separate category using the term 'system innovation'. System innovations include organisational, technological and process changes, and describe systemic changes linked to agricultural and environmental systems. The system innovation, however, defines transitions at the level of societal functions (Geels 2005; Klerkx, Aarts & Leeuwis 2010; Klerkx & Leeuwis 2009), while the case study innovations describe the transition at a level of ecological functions. By looking at the potential of an innovation for contributing to a transitional change towards sustainable agro-ecosystems we propose a new category that captures the capacity to use agro-ecological principles for engineering the transition to sustainable agro-ecosystems along a gradient of rising complexity on the one hand and potential interfaces for ecosystem interventions on the other (**Fig. 4**).

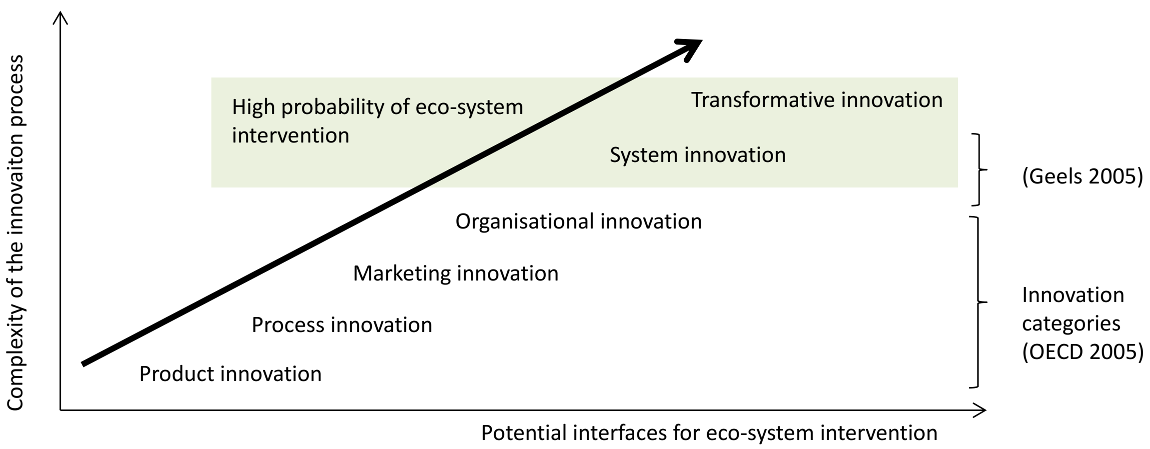

Fig. 4 Rising complexity in innovation categories by potential interfaces for eco-system intervention.

In taking a closer look at what we termed as 'transformative innovation', we find that all four case studies address a change in the wider sector- and region-related agricultural production process. Each case study thus involved a systemic shift that can be described – in rising complexity – as a) re-organisation of production processes, b) co-operation between and merging of production processes from different agricultural sub-sectors, c) re-organisation of production and marketing by integrating existing value chains, and d) co-operation between and merging of production and marketing across different agricultural sub-sectors by re-organisation and new definition of production processes and value chains.

As was described in the results section, all four case studies did not reach market viability within the time of analysis. In the following, we therefore discuss what characteristic features in the case study innovations contribute to the rising complexity that leads to time lags and impediments during innovation development. We discuss four characteristic features that we understand as specific to innovations that aim to contribute towards a transition to sustainability, and that require an early integration of target knowledge to facilitate the innovation process: a) potential for targeted disruption, b) eco-functional impact, c) profit downshift effect, and d) impact assessment complexity. An overview on how the case study innovations relate to each of these characteristic features is illustrated in **Table 6**.

Potential for targeted disruption

Innovations are generally assessed for their disruptive potential, thereby addressing the capacity of the innovative approach to achieve systemic change based on technological progress. In the case studies, the systemic change is explicitly the targeted transition to sustainable agro-ecosystems. The potential for targeted disruption therefore refers to the capacity of the innovation to contribute to the transition by its disruptive features, and its capacity to challenge existing production systems. Existing production systems, and thus also traditional pathways of innovation development, are protected by existing individual interests, by competition between (sub-)sectors and regional entities, by the existing lock-in effects and by economies of scale.

The disruptive features can be low, as in the EVI case, where the work flow of planting and harvesting is hardly affected by introducing the biological control agent. They can also be very high, as in the example of HayHeat, where land ownership and property rights are affected, new material flows between farmers and energy producers will be created, and value chains need to be redefined. Low disruptive features are expected to lead to fewer barriers during implementation due to a better systemic fit, while high disruptive features meet resistance at sector and region levels.

The relevance of the approaches developed in the case study for sustainability is reflected by a wide interest across sectoral and regional groups of actors documented during the analysis. However, although regional and sector benefits, as well as environmental benefits at the level of the society become apparent, co-operation between actors is not an automatism (Guerin 2001). Strong motivational drivers and incentives are required to integrate interests at strategic levels as well as in practical implementation (Nidumolu et al. 2009). The case of EiCare exemplifies how incompatibilities of the alternative production process with existing value chains lead to challenges in responsibility and ownership in regard to the innovation management. While the individual farmers generally lack the necessary risk capital to drive the innovative approach (Labarthe &

Table 6 Potential of case study innovations for contributing to a transitional change.

Case Study		Description of the systemic shift	Potential for targeted disruption	Eco-functional impact	Profit downshift effect	Impact assessment complexity
1.	EVI	Re-organization of production by actors in one sector (production shift)	⇘	⇨	⇘	⇗
2.	ASTAF Pro	Re-organization of production by actors across sectors (production merge)	⇨	⇨	⇨	⇗
3.	EiCare	Re-organization of production and marketing by actors in one sector (value chain shift)	⇨	⇗	⇗	⇗
4.	HayHeat	Re-organization of production and marketing by actors across sectors (value chain merge)	⇗	⇗	⇗	⇧

Laurent 2013), third parties will calculate their risks at a very high level, while research organisations generally see developmental activities to be out of their scope of activities. The benefits of the innovative approach can thus only be calculated at the societal level, which moves the responsibility to the policy sector. This requires the development of incentives at the governance level that widen the scope for implementation based on calculated societal benefits of the innovative approach.

Eco-functional impact

With all four case studies setting out to contributing towards sustainable agro-ecosystems, all approaches contain elements that each can lead to a positive or negative ecological impact, and consequentially contain an environmental risk. Thus, adjustments to the locality of implementation will be required in every new case of implementation, involving assessment and testing to match the innovative approach with the situation in place. Scientific analysis can improve the situational understanding as to which elements need to be maintained, and which elements need to be adjusted to contribute to sustainable agro-ecosystems (see e.g. Turnheim et al. 2015). In the case of EVI, for example, newly available genetic analyses for rapid soil assessment help to assess *Verticillium*-infestation, but also the effectiveness of the biological control agent.

Farmers operate in a complex environment that is determined to an increasing extent by individual skills, local networks, cross-sector cooperation and policies defined at local, national or European decision levels. The tacit knowledge of the farmers is required to adjust the innovative approaches to every single locality of implementation, where scientific analyses fall short, for example due to (as yet) unavailable assessment methods in the natural sciences.

Profit downshift effect

Sustainable agro-ecosystems are believed to link resource conservation with economic competitiveness. An integration of processes is expected to lead to an improvement of the agro-ecosystem. However, the integration of processes leads to delays in reaching an economic break-even, particularly in those cases with high disruptive features and high eco-functional impact. Both characteristics are linked to higher financial risks, trust issues and cautiousness in approach.

Based on the early integration of sustainability goals in planning, the delay in reaching economic break-even can be calculated (e.g. Cavael 2016). This will enable the development of (financial) measures and policy instruments to overcome risk precautions at the individual level.

Impact assessment complexity

The more original an innovation, the more difficult it is to communicate its benefits and impacts due to the many unknowns that an innovation naturally contains (Ben-Haim 2013). The implementation of an innovative approach in the agricultural sector will be perceived differently by other, adjacent sectors concerned (i.e. forestry, water management, nature conservation, recreation, tourism, energy production, food processing, transport and infrastructure, housing, spatial planning, etc.). Due to multi-causal ecosystem dynamics, impacts of change can be remote in space and time from the events that we wish to anticipate. Thus transfer of research to the land use sectors involves a high grade of uncertainty on top of the general risks in the course of proving concept, feasibility and market entrance. This seems to reduce the pull factor generally experienced in innovation processes, where consumers react to innovative approaches, and take up a new product or service. All four case study innovation required extensive "push"-activities, because they concerned complex direct and indirect impacts that could not be easily followed up by consumers or decision makers. Furthermore, they contained non-market or indirect market benefits in terms of a more ethical, healthy or environmentally clean production that also presuppose the concern of consumers for sustainability issues. The market "push" activities, however, require additional strategic planning based on an assessment of contextual factors defined by policies, regional setting and local resources (OECD 2013). With a rising complexity of the innovative approach, the contextual factors that primarily require assessment multiply. The amount of data that would have to be handled at the front end of innovation would thus benefit from currently proliferating approaches such as wider participation via open innovation (Chesbrough 2017), or information technology (big data) approaches (Gordon et al. 2015). Alternatively, the continuous reflection and calibration of intermediate results with the actors applied in this study is found to provide a practicable way to achieve qualitative research synthesis (Blackstock et al. 2007; Denyer & Tranfield 2006).

Conclusion

The European farming sector is a highly innovative, competitive and interconnected sector much committed towards technological innovations and experimental developments. It fulfills a key function in adding value to regional and national value chains, maintaining traditional cultural landscapes and providing local jobs for downstream services, trade and refinement industries. Production in this sector is work intensive and at the same time vulnerable to environmental factors such as impacts from temperature, humidity or spread of pathogens as well as to short term market shifts. Thus innovation-driving activities gain importance to master the current challenges due to demographic, societal and climatic changes.

The case studies emphasise that agriculture is a highly complex sector for innovation. Due to its links to many adjacent sectors, systemic foresight requires an involvement of sectors and policy areas that are concerned with impacts and effects at different time horizons and spatial scales. This in turn requires methods and research disciplines that address not only the different levels of analysis, but also the integration of data for innovation management. While for example agricultural policies are increasingly determined by European policy making, actors and stakeholders are largely embedded at local level. Next to policy makers and researchers, these actors include entrepreneurs, non-governmental organisations, and the civil society. A divergence of interests within the system has an effect on knowledge transfer processes, visualisation of problem states and the translation of claims between groups of actors.

Much literature concerned with front end innovation is linked to the context of industry. With agriculture being equally dependent on natural resources as well as on skills and abilities, systemic foresight processes at the front end of innovation development are found relevant in planning, risk mitigation and speeding up of the process. To this end, front end activities would require an institutionalisation within the existing knowledge networks, for example the agricultural research organisations.

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Field Application of Non-Pathogenic *Verticillium dahliae* Genotypes for Regulation of Wilt in Strawberry Plants

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ABSTRACT

Verticillium dahliae induced wilt disease in strawberry can cause severe yield losses and thus lead to inevitable negative economic impacts. Inoculation of plants with non-pathogenic strains of *Verticillium* was conducted as a biologic control agent (BCA) according to the concept that preoccupation of the ecologic niche rendered strawberry plants immune to infection with soil-borne pathogenic *Verticillium*. This concept was tested for economic viability in a field trial under commercial conditions. Results were reported for 2 years of field trials under practice conditions in two locations in Brandenburg, Germany. Inoculation was shown to have a positive effect of 20% of plants, while 30% of plants remain unaffected and of equally high vitality. However, 50% - 60% of plants were impacted negatively, showing severe wilt symptoms up to total loss. The characteristic progression of wilt symptoms suggested an infestation caused by *Phytophtora* sp. and other pathogens. Further results showed that the main factor of the side effects was caused by different qualities of plant material in interaction to the inoculation with the BCA and only to a minor extent depended on pre-infestation of soils. We conclude that specific conditions, such as certified plant material or soil analysis for other pathogens besides *Verticillium*, avoided these side-effects relevant for commercial farming.

Keywords: Antagonism; Biological Control Agent; Wilt Regulation; Verticillium; Strawberry

1. Introduction

Wilt symptoms caused by the soil-borne saprophyte *Verticillium dahliae* account for severe yield losses in numerous culture and cash crops and raise the risk of fruit and vegetable production. Albeit strawberries are a cash crop of intermediate economic importance in Germany, the market for regional fruit is not saturated and strawberry cultivation has expanded in Germany over the last few years to coverage of 14,000 ha in 2011. *Verticillium dahliae* is the most important pathogen in strawberry production besides *Phytophtora cactorum* [1], and is explicitly quoted as a major risk that stands against an increase in production by horticultural services, experimental research and growers. Preventive measures to avoid plant infection are expected to significantly contribute to sustaining strawberry cultivation as a culture crop in traditional fruit producing regions such as the region of Brandenburg that surrounds Berlin, Germany.

The incidence of the fungus in soils is of irregular intensity and can be unevenly distributed within a plot [2] while plants show a varied tolerance towards fungal colonization [3]. Interrelated with the occurrence of asymptomatic host plants [4] this entails the intricacies of a meaningful assessment of risk in fruit production. Furthermore, growers encounter difficulties in avoiding or restoring infested sites, partly due to the long term persistence of microsclerotia (MS) in the field and partly due to the limited availability in cropland within the individual farm or even within a region [5]. As a result of the phase out of biocides chemical biocide usage (EU regulation No. 528/2012) and an absence of alternative control measures or management strategies [6], a practicable method of wilt regulation is strongly demanded by farmers in Germany, and is thus subject of this study.

An extensive review on Verticillium wilt disease in olive describes a multitude of factors influencing disease onset, progress and severity, including agronomical factors such as irrigation, fertilization and soil management as well as environmental factors such as temperature, edaphic features and biotic interactions [7]. The authors conclude that symptoms depend mainly on cultivar susceptibility, inoculum potential in the soil and environ-

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mental conditions. The latter strongly correlates with cultural practices employed in commercial agriculture [8]. From a farmer's point of view the synthesis of current knowledge implies an estimation of soil quality as well as plant quality and a selection of plot management measures to be applied before, during or after planting in order to influence environmental conditions in favor of wilt regulation. All practical approaches are addressed in scientific research.

For many years, analysis of *Verticillium* infestation in soils based on wet-sieving methods as a risk prediction method provided useful to strawberry growers in spite of evident limitations such as a dependence on weather, soil type and preceding crops [2,9]. Progress was achieved with the development of qPCR methods to detect Verticillium microsclerotia (MS) in soils [10]. This technology is currently being optimized for in vivo detection in plants [11].

Incidence and severity of *Verticillium* wilt are associated with crop history, *i.e.* the succession order of susceptible and unsusceptible crops grown on site. Although this is found unreliable for wilt risk assessment [2], it has led to numerous studies of bio-fumigation and crop rotation effects in order to reduce inoculum potential, e.g. [12], albeit with limited overall effect in practice [5]. Other management practices involve manipulation of the soil temperature, handling of plant residues or reducing nitrogen fertilization [13,14].

Plant resistance is addressed on a regional basis by regularly testing cultivar susceptibility and resistance in experimental research involving bioassays, e.g. [15]. However, comparison of results between regions shows heterogeneities and thus does not lead to an overall approach. Corresponding to the understanding that wilt disease occurs more frequently in vegetatively propagated crops [2], further improvements of micropropagated plants were tested by inoculating with different species of arbuscular mycorrhizal fungi, but showed no definitive growth trends [16].

Biological control agents (BCAs) can manipulate the plant rhizosphere by inoculation of plant parts with specific microbes before or after planting by utilizing either antagonistic effects or vitality boosting properties, e. g. due to improved accessibility of nutrients. Studies were conducted with various species, e.g. Pseudomona spp. [17], rhizobacteria isolates [18] or soil-associated fungi [19]. A minor subset of researchers in the field of BCAs focuses antagonistic effects of *Verticillium* subtypes for Verticillium control. Tyvaert reports results from an interaction of Verticillium longisporum with *Verticillium* Vt305 isolates used as a BCA in cauliflower plants [20]. Host specificity of Verticillium isolates and varying effectiveness in pathogenicity on strawberries are well-known [21,22].

Although the majority of the above mentioned studies incorporate field trials, they remain isolated applications only indicating the potential for a holistic strategy that can be applied in the different micro-environments of genuine commercial practice. An upscale or roll-out of methods to meet practice conditions has not taken place to the extent that growers can incorporate scientific progress on wilt management when installing a new plantation, and the question how to keep stock in spite of wilt disease remains unresolved. The need for a validation of methods for wilt management is increasingly being articulated by German farmers. Therefore, the objective of this study was to test the potential use of an innovative management measure to regulate wilt caused by *Verticillium* under conditions of commercial production.

The proposed measure is based on findings that relate wilt incidence to changes in plant microbial population structures and the observation that wilted plants are colonized by a different number and composition of subtypes with different pathogenicity compared to healthy plants. The BCA (EVI) consists of three non-pathogenic genotypes of *Verticillium dahliae* shown to successfully control wilt symptoms in strawberry plants in different climate regions [23-26].

Primarily, the focus of this study lies on the technical applicability of inoculation with conidiophores in the common work routine of planting to demonstrate the proof-of-concept independently of field localization, environmental conditions and field management. Monitoring of plant vitality is conducted to reveal plant reactions in dependence of the interaction between soil, plant and the BCA in order to show the potential of the concept by using a parameter directly usable by the strawberry growers for economic analysis.

2. Methods

2.1. Experimental Sites

Two production sites (A, B) that were subject to similar conditions in commercial practice were chosen for experimental testing in Brandenburg, Germany, with a linear distance of 114.8 km (38.9 km west and 79.9 km south-east of Berlin) (**Figure 1**). Both sites have a history of strawberry production and were characterized as highly infested with Verticillium by the growers. Field inspection conducted in 2011 showed detectable wilt infection on old growth. Spot samples analyzed for *Verticillium dahliae* confirmed similarity in terms of infestation with microsclerotia for both locations (15 - 20 microsclerotia per gram soil).

Plot A was loamy sand (10% silt, >80% sand) (Soil information system Brandenburg LBGR), located at latitude 52.45˚, longitude 12.80˚, with an elevation 29 - 35

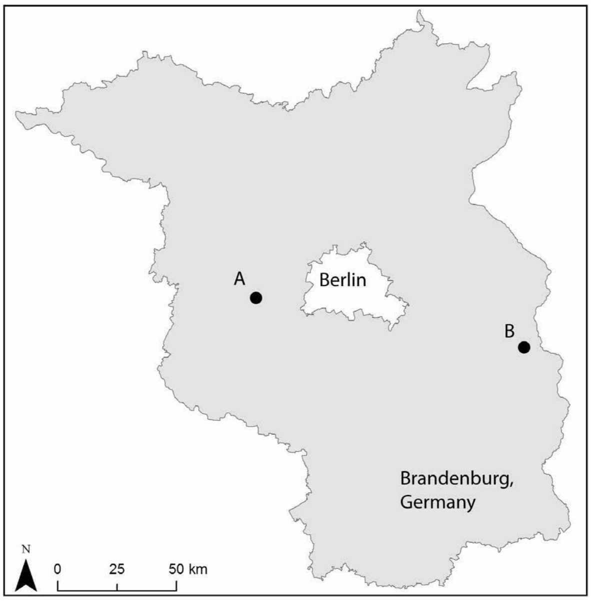

Figure 1. Location of production sites used for field test.

m and a precipitation rate of 592 mm with an average temperature of 8.7˚ (30 years mean). Plot B was loamy sand (silt 10%, sand >85%), located at latitude 52.28˚, longitude 14.75˚, with an elevation of 58 - 61 m and a precipitation rate of 443 mm with an average temperature of 8.5˚.

For each site, two plots were set up in direct vicinity in 2011 (A_{2011}, B_{2011}) and 2012 (A_{2012}, B_{2012}), thus allowing to test different micro-environments per location.

2.2. Molecular Verticillium Detection

Molecular detection of soil-borne *Verticillium* was performed once in 2011 in order to confirm personal communication with the growers by using a *Verticillium*-specific polymerase chain reaction (PCR) assay with primers allowing accurate detection of *Verticillium dahliae* including lineages of A1/D2 and A1/D3 *Verticillium longisporum* [27]. Soil DNA was extracted with Nucleospin-Soil DNA Extraction Kit (Macherey-Nagel GmbH, Dueren, Germany) according to protocol. Quantification of *Verticillium* was achieved using a 5x hot firepol Evagreen qPCR mix + ROX (Solis Biodyne, Tartu, Estonia) (AB 7500 fast, Life Technologies Corp., Carlsbad, CA, USA) with two independent calibration curves derived from *Verticillium dahliae* microsclerotia. PCR amplification was performed with an initial denaturation at 95˚C for 10 min, followed by 40 cycles of 0:15 at 95˚C. PCR was carried out in 20-µl reactions with 5 pmol of each primer: Forward primer VDP1 (5’-TCTACTCATAAC CCTTTGTGAACCA-3’), reverse primer VDP2 (5’-ACT CCGATGCGAGCTGTAAC-3’).

2.3. Test Design

The test design was developed under consideration of irregular dispersal of fungi in soils and erratic intensity of soil infestation within fields. Taking the individual planting techniques used by the growers into account, we designed experimental rows and thus refrained from the traditional randomized block design. In consequence, plants with EVI treatment were located in direct neighborhood of control plants. The main strategy was to have a neighborhood comparison with EVI treated plants and the control and to observe either constant or differential effects of plant reaction to EVI by comparing pairwise among each variant. Control plants were expected to be susceptible in contrast to EVI treated plants. Testing was conducted in two successive years from March till September 2011 and 2012.

Plot A: Planting was conducted by a four-hole-plant-logger machine fed manually (four rows simultaneously) providing an in-between plant distance of 30 cm. Planting was conducted on June 3rd 2011 (A_{2011}) and June 14th 2012 (A_{2012}). Test design for A_{2011} comprised 16 rows with four double-rows with EVI treatment next to control plants, each double-row alternating with two intermediate rows. Each row contained approx. 420 plants. Test design for A_{2012} comprised four rows with two double-rows. First double row alternating EVI and control, the second double-row alternating EVI + root cut and control + root cut. Each row contained approx. 220 plants.

Plot B: Planting was conducted by hand following a three-furrow hole puncher providing an in-between plant distance of 33 cm between plants (three rows simultaneously). Planting was conducted on May 19th 2011 (B_{2011}) and May 25th 2012 (B_{2012}). Test design for B_{2011} comprised four rows with two double-rows alternating EVI and control. Each row contained approx. 400 plants. Test design for B_{2012} comprised 3 rows alternating control, EVI, control + root cut, thus flanking one row with EVI treatment with one row of control and one row of control + root cut on either side. Each row contained approx. 400 plants.

Plot C: For a gain in clarity, we set up a third plot on the institutes premises on virgin soil with no known history of cultivation and no indication Verticillium infestation in 2011.

2.4. Plant Material

Treatments were performed on strawberry plants (*Fragaria* × *ananassa* [Duchense] Decaisne & Naudin [family: Rosaceae]) using “Elsanta” which was prioritized by regional growers as a preferred cultivar in fruit production due to its favorable characteristics for trade (personal communication). The cultivar was found highly susceptible to *Verticillium* in this region, and was thus used for testing in correspondence with findings that aggressiveness in isolates is most significantly expressed in the highly susceptible genotype cultivars [28]. Plant material for field testing was retained from the batch prepared for planting for plots A and B. Plant material **a** and **b** was available in tested quality A++ (A2011, B2011) and A+ (A_{2012}, B_{2012}). For Plot C own plant material was used (**c**), available in a tested quality A+++, as well as plant material in tested quality A++ taken from leftovers of plant material from Plot B, source **b**.

2.5. EVI Treatment

Treatment of plants was conducted after removal from cold storage and immediately before planting to reproduce actual work flow. We inoculated the plants under controlled conditions, while preparation of beds, planting, irrigation and further treatment were carried out by the growers according to individual techniques.

EVI contained a mixture of non-pathogenic strains of *Verticillium dahliae* prepared in cooperation with ABiTEP GmbH, Berlin, Germany for investigating technological upscale in fermentation. The soluble compound included an equal proportion of spores from each of the three isolates of *Verticillium dahliae* resulting in a final concentration of more than 10^6 conidia spores/ml per strain.

Plant roots were immersed in an aqueous suspension with a concentration of 1×10^5 conidia spores/ml and 5×10^5 conidia spores/ml corresponding to findings that inoculation with a spore suspension of about 10^6 conidia per ml using a root-dip technique was efficient for affecting plant reaction to Verticillium dahliae isolates as well as for precisely distinguishing tolerant from susceptible cultivars [21,22,29]. Inoculation by root dip was tested for 30 min and 40 min in solution with best results at 30 min. Inoculation was also tested for plant material with clipped roots (root cut) and for plant material without infringement.

2.6. Inoculation Effectiveness

Regular, clipped and inoculated plant material was retrieved from the batch and subsequently stored at 4˚C for microbiological analysis. Adhering conidiophores on the root surface were determined by shaking the roots in 0.9% solution of sodium pyrophosphate under addition of sterile 2 - 5 mm quartz gravel for 15 min. This suspension was plated in different stages of solution to identify the number of Verticillium colonies. The number of conidiophores inside the roots was determined by plating the rinsed roots on culture medium in 0.5 cm pieces. Analysis was conducted for the different plant materials. Plant material **c** had an average root weight of 12.7 g; plant material **a** and **b** had an average root weight of 7.4 g.

2.7. Plant Vitality and Disease Assessment

Plant vitality was rated by visual monitoring performed 3 - 3.5 months after planting in each year and for each plot (A_{2011}: August 22nd 2011, A_{2012}: August 23rd 2012, B_{2011}: August 5th 2011, B_{2012}: September 12th 2012). Plant vigor was scored on a scale from 0 (dead wilted plant) to 9 (healthy with no wilt symptoms). Plants with a score >7 were considered vital, according to the growers rating of plants for commercial use.

Development of wilt was assessed and recorded for all plants treated with EVI and the control plants in the test design. Plants were rated pairwise across rows. Intermediate rows between test rows were observed for peculiarities but not rated. Visual rating was later extended to record symptoms for other pathogenic diseases (Nematodes, *Alternaria* sp., *Diplocarpon earliana*, *Mycosphaerella fragaria*, *Phytophtera* sp.).

2.8. Re-Isolation

Plant samples were cut into 1 - 2 cm pieces. For surface sterilization pieces were initially treated by stirring in Iso-propanol followed by distilled water twice and subsequently with hydrogen peroxide. Further the samples were dried for few seconds on a sterile filter paper and treated again with water inside a vacuum chamber. The samples obtained from vacuum glass filter were dried on sterile filter paper and were divided into four pieces. These small pieces were transferred carefully on to potato dextrose agar media. The plates were incubated at 25˚C until the colonies are formed. *Verticillium dahliae* and *Alternaria* sp. were identified by phenotypical features in microscope analysis.

3. Results

Technical applicability of inoculation with conidiophores in the common work routine of planting was found feasible. Since root dipping is a common measure to be undertaken before planting, application of the measure in the field allowed a fluent integration into the work flow during planting.

Inoculation effectiveness was given, whereas plant material with root cut showed no differences in colonization of the fungus compared to plants with roots kept intact. Plant roots were colonized after 30 min of root dip; however the fungus could not be retrieved from petioles in both cases.

An inoculum concentration of 1×10^5 conidia spores/ml was found to be sufficient. Plant material showed adherence rates of 2.1×10^5 (source a) and 1.1×10^5 conidiophores per root (source b) on the root surface. Doubling the inoculum concentration to 5×10^5 showed no increase in colonization for both sources of plant material. A saturated concentration was observed at 1.5×10^4 conidiophores per gram root fresh weight.

3.1. EVI Effect on Plant Health

Demonstration of the proof-of-concept in different spatial settings independently of environmental and technical variances and crop treatment was not successful in light of economic viability. Overall plant health could not be improved with the treatment and the number of dead and wilted plants in the EVI treated rows added up to approx. 50% - 60% for both locations and both years. Concluding from the number of dead plants in the EVI rows compared to the control the growers stated that complementing soil parameters with high quality plant material was experienced more stable and that treatment with EVI was no option for future use.

Plants treated with EVI showed 5% - 30% dead plants compared to 1% - 5% dead plants in the control on both Plot A and B (**Tables 1** and **2**). Vitality rating added up to the same overall result for both plots, but the pattern of dead and wilted plants in 2011 did not correspond with the pattern found in 2012. Vitality rating also showed that EVI treatment did not have homogeneous effect within one plot as some areas were free of dead plants.

A_{2011} showed an average vitality of 4.5 after EVI treatment due to the high number of dead plants of over 30%. Average vitality without consideration of dead plants slightly decreased from 7 to 6.5.

A_{2012} showed an average vitality of 7 after EVI treatment. The effect from 2011 could not be repeated in 2012. In 2012, we found a strong correspondence of vitality with the root cut plants. Average vitality excluding dead plants however showed no differences between EVI treated plants, control or control + root cut.

Table 1. Plot A vitality rating.

Plot A	Plant material 3.5 months after planting			
	Vitality rating	*Control*	*Control + root cut*	*EVI + root cut*
2011	% dead plants		6.9/5.1	35.2/31.6
	Ave. plant vitality		6.8/6.7	4.6/4.5
	Vitality excl. dead		7.2/7.0	6.8/6.3
	Total no. of plants		346/354	344/370
2012	% dead plants	2.1	5.0	5.4
	Ave. plant vitality	7.6	7.2	7.0
	Vitality excl. dead	7.8	7.6	7.5
	Total no. of plants	384	382	390

Table 2. Plot B vitality rating.

Plot B	Plant material 3 months after planting			
	Vitality rating	*Control*	*Control + root cut*	*EVI + root cut*
2011	% dead plants	1.1/1.1/3.6/5.3		1.3/5.3/3.6/12.5
	Ave. plant vitality	7.5/7.6/7.0/6.7		7.2/6.5/6.4/5.5
	Vitality excl. dead	7.6/7.7/7.2/6.8		7.2/6.8/6.6/6.1
	Total no. of plants	377/376/389/263		377/374/389/263
2012	% dead plants	4.2	3.4	34.0
	Ave. plant vitality	8.2	8.2	4.4
	Vitality excl. dead	8.5	8.4	6.9
	Total no. of plants	191	210/204	194

B_{2011} showed a decrease in vitality along a gradient crossing the rows (7.5/7.6/7.0/6.7). Death rate increased running counter to the gradient (1.1/1.1/3.6/5.3) and leading to an overall decrease in average plant vitality from 7 to 6.5. Average vitality excluding dead plants from the analysis, showed a milder effect of decreasing vitality from 7 to 6.

B_{2012} showed a very high portion of dead plants adding up to more than 30%, thus showing a similar effect to A_{2011}. However, the effect of root cut did not show the same impact compared to A_{2012}.

Altogether, vitality rating showed an atypical course of disease not common for *Verticillium* wilt such as rapid wilting. Root cut showed a slight dampening in plant vitality in the field trials but the effect was not reproducible, suggesting an influence of soil microbes other than *Verticillium* to colonize the plants.

Rating conducted to assess the indication of other pathogenic diseases showed considerable increase of pathogens of other type and culture. Results showed 30% - 40% latent infection rate of vital control plants caused by *Phytophtora* in both years. Strongly wilted and dead plants (rating grades 0 - 3) showed an infection rate of *Phytophtora* at 80% - 100% (rated by red colored tissue at section of petiole). In the EVI treated plants, the ratio of dead plants caused by *Phytophtora* infection was up to 30% compared to 1 - 5 in the control. The potential is more or less evident dependent on location and year.

3.2. Adverse Effects and Plant-Soil Interaction

For every pair of plants according to the sequence of matches along the rows, the reaction of plants towards EVI treatment (indicated by the vitality rating on a scale of 0 - 9) was quantified by calculating the difference between vitality of the EVI treated plant and vitality of the neighboring control, in this case a priori excluding dead plants to avoid a bias from other pathogens.

Pairs that show no difference in vitality were marked as neutral. Pairs that showed a positive vitality of EVI compared with control were marked as positive. Correspondingly, pairs that showed a negative vitality of EVI compared to control were marked as negative.

In the following, data is shown for 2011and 2012. The positive effects showed a consistent boost of vitality of 2 - 3 grades in rating, while the negative effects also showed certain conformity of reduced vitality of 2 - 5 grades in rating (**Tables 3** and **4**). The positive effect was shown in approx. 20% of pairs, thus referring to an effect in inoculated plants.

An effect of plant material was noticeable in the visible curb of vitality. Visual inspection of the sites had also shown the before mentioned gradient in wilt infection crossing rows.

Plot C conducted in parallel on the premises of the institute was now drawn on, to analyze whether indications of influence either from observed differences in the micro-environment determined by the soil or from observed disparities determined by different quality of plant material could be substantiated (**Table 5**).

Results showed that independent of plant material a slightly positive effect of EVI treatment can be proved based on the rating of plants pairwise across rows in Plot C, which was not pre-infested with Verticillium. Analysis also showed a strong effect resulting from plant material **a** which had a strong negative impact on the vitality of EVI treated plants (reduced vitality to 5.5) and in the extent of plants affected (40% below 7 and 12% dead). Rating from EVI treated plants from plant material **a** in Plot C was conform with A_{2011} (60% below 7% and 33% dead). Plant material **c** showed none of these effects.

A more detailed analysis of the additional rating conducted to assess the incidence of other pathogenic diseases showed not only an increase of microbes on the whole but also significant shift in microbe populations in the EVI treated plants: the microbe population was found to be of a different composition compared to control.

Pairs of plants were retrieved from the field at the date of vitality rating. Pairs were selected individually to analyze neutral, positive and negative influence of treatment

Table 3. Plant reaction rating (A).

Plot A	Plant material 3,5 months after planting			
	Vitality rating	*EVI*	*EVI + root cut*	*Control + root cut*
2011	% plants neutral		46/39/ 32/25	
	% plants positive		20/17/ 24/24	
	% plants negative		34/45/ 45/52	
	Vitality (neutral)		7.9/7.9/ 7.6/7.7	
	Vitality (positive)		8.0/7.7/ 7.3/6.5	
	Vitality (negative)		5.7/4.9/ 4.9/4.0	
2012	% plants neutral	17	15	44
	% plants positive	24	19	34
	% plants negative	59	66	22
	Vitality (neutral)	8.2	8.4	8.8
	Vitality (positive)	7.3	7.2	8.7
	Vitality (negative)	6.6	6.4	7.8

Table 4. Plant reaction rating (Plot B).

Plot B	Plant material 3,5 months after planting			
	Vitality rating	*EVI*	*EVI + root cut*	*Control + root cut*
2011	% plants neutral		21/20	
	% plants positive		21/19	
	% plants negative		57/61	
	Vitality (neutral)		7.6/7.3	
	Vitality (positive)		7.3/7.3	
	Vitality (negative)		4.4/4.1	
2012	% plants neutral		51	61
	% plants positive		29	18
	% plants negative		20	21
	Vitality (neutral)		7.9	8.0
	Vitality (positive)		7.9	8.0
	Vitality (negative)		5.5	6.4

Table 5. Plant reaction rating (Plot C).

Plot C	Plant material 3 months after planting		
	Vitality rating	*Plant material b*	*Plant material c*
2011	% Dead plants	12/8/17	0/0
	% plants neutral	56/58/58	92/82
	% plants positive	5/0/4	4/9
	% plants negative	39/42/38	4/9
	Vitality (neutral)	7.6/7.1/7.9	8/7.9
	Vitality (positive)	9/-/8	8/8
	Vitality (negative)	5.7/5.8/4.9	7/7
	Total no. of plants	24/26/24	26/24

in EVI treated plants, each against the neighboring control plant. Petioles from control plants showed 59% no growth, EVI treatment halved this effect to 35%, showing that colonization on the whole had doubled. Besides an impact on quantity of microorganisms, the specter of groups was changed and more diverse (**Table 6**).

4. Discussion

Vitality rating led to results contradicting previous experiments in laboratory, greenhouse and field conducted in 2005 [24,25]. Consequently, evidence for a proof-of-concept independently from spatial settings is not given. The application of a BCA in form of inoculation with apathogenic *Verticillium* strains is found to show a different trend neither expected nor estimated when applied under commercial growing conditions out of the laboratory.

Nevertheless, the positive effect of the BCA can be shown in the detailed analysis of pairwise plant rating. The developed test design in rows was found extremely useful for this detailed plant-to-plant comparison along local unknown complex differences in interactions.

Table 6. Ratio of re-isolates in plants with EVI treatment + root cut (r.c.) and control (C) as seen from petioles (A-L phenotypical characterization of fungal groups).

	Re-isolation of microorganisms from petioles by phenotypes (ratio in %)					
	Plot A		*Plot B*		*Plot C*	
No. of plants/pieces	16/64		20/80		10/40	
	EVI + r.c.	*C*	*EVI + r.c.*	*C + r.c.*	*EVI + r.c.*	*C*
Bacteria	5	0	15	14	5	6
A (V. dahliae)	14	19	16	22	17	0
B (Alternaria)	7	8	4	5	17	0
C	12	5				
D			6	5		
E		2				
F	5		3	3	3	
G	2		7	4	5	
H	2		3	2		
I			3	3		
J			3		2	
K						5
L					5	
M	18	2	11	8	19	2
No growth	35	64	29	34	27	87

4.1. Application of the EVI Control Agent

Based on the outcome that regulation of wilt was successful, but enhanced the pathogen background to a complex course of diseases, further technological development of EVI application is currently found to be impaired by side effects and quality of plant material.

EVI is found to disrupt the given plant-soil interaction (as in control) and lead to a strong interference of other pathogens involving for instance *Alternaria* sp. and *Phytophtora* sp. The found change in quantity and diversity of microbial composition in the plant triggers a sequence of diseases leading to plant loss. Adverse effects differ from location to location and from year to year resulting in different proportions of dead plants. Successful field application of EVI will depend on further research and monitoring of interdependencies in soil-borne diseases in plants and plot in order to address the complex interaction of such side effects in wilt regulation.

Phenomena in the field influenced by natural environment factors such as temperature, humidity, microbiological interactions resulting in changes of pathogen concentration in the plant surrounding can be partially reduced by triennial seasonal observations that make evaluation more reliable but also more costly and time-consuming [29]. However, plant-soil interaction is a black-box when it comes to application of regulation measures under commercial conditions. Key factors for such side effects are found in the pre-infestation of plant material or soil by other pathogens. For an application of EVI we were able to show the significance of determining interactions with other pathogens because of results that show an influence of inoculation not only on the plant system but also on the microbial system.

Other unpredictable results were found, e.g. in an influence of wilt development by nematode infestations in soil [2] or in microbiological interactions resulting in changes of pathogen concentration in plant surroundings [29]. Chemical fumigants can also strongly influence the microbial interactions by being partly selective to microorganisms that could increase pathogen re-colonization [30]. This effect has been studied in the field applying the fumigants to strawberry fields under commercial agricultural practice [31].

4.2. Role of Plant Material

Results strongly suggest that the course of disease was triggered by the BCA application but was in effect caused by other pathogens in the soil. In our case, the latent infection in a large part of control plants caused by *Phytophtora* (30% - 40%) was laid open by the treatment with the BCA. Certified plant material of very high quality did not show the same side effects but showed results as we had expected from our previous studies.

The homogeneity and quality of plant material is one significant factor, and therefore one condition, for a reliable application of BCAs under commercial conditions. Additionally, the level of quality in strawberry plant material is also economically relevant regarding the co-import of pathogens by importing plant material [32]. The relevance of infection spread by nursery plants was described for olives already in 1993 [33]. For an application of BCAs under commercial conditions we therefore suggest to use certified plant material tested not only for *Verticillium* but also for other pathogens such as *Phytophtora* and *Alternaria*.

4.3. Role of Pre-Infested Soils

Under conditions of pre-infested soils on middle to high level as in Plot A and B (15 MS/g), re-isolation showed *Verticillium* infestation of 20% in the control plants. EVI treated plants likewise show a positive effect of approx. 20%, no effect on *Verticillium* free soils as in Plot C. On not pre-infested soils EVI had no impact. This was shown independently of the plant material.

5. Conclusions

The concept of apathogenic *Verticillium* application was found to have specific positive effects on the occurence of *Verticillium* wilt under commercial conditions. However, the effect is overlaid by the interaction of the BCA with other pathogens in the soil or in plants induced by the EVI treatment. Any manipulation of plants such as root cut can increase the side effects extra.

Application of a BCA in strawberry plantations as shown here needs additional specific requirements, such as certified plant material or soil analysis for other pathogens besides *Verticillium* to obtain healthy plants.

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Sustainability assessment of agro-ecological innovations at territorial and value chain scale

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ABSTRACT

With growing awareness of global environmental problems caused by agricultural production, producers and retailers increasingly strive to introduce sustainability led changes at farm level. A propagation of cooperative approaches has led to a diversity of niche developments worldwide with multiple but small-scale effects on sustainable land use. The potential for a broader impact is often inhibited by the failure to appropriate the value creation necessary for a long term establishment in the market. The study reported here was conducted as an intermediate step in developing assessment and management tools for innovations in a smallholder farm environment. Semi-structured interviews were analysed based on network analysis, content analysis and case comparison in order to answer the following questions:
What environmental, economic or social values are expected from the innovation as a contribution to sustainable land use?
What is the potential and what are the limits of integrating sustainability assessment into innovation management processes in regard to value chain and territorial approaches?
Ethical issues and diversification in farm structure were found more relevant to the sector oriented approach of poultry production. The regional case differed in highlighting consensual strategies, a strong recognition of future generations, property rights and provision making. Issues of local added value, closed circular systems and capacities for development were found to link both territorial and value chain approaches. The approach is discussed for its potential in making explicit the societal and environmental value creation and for fulfilling aspects of plausibility and applicability by the practitioners involved in the project.

Keywords: sustainability, innovation management, content analysis, transdisciplinary research, agricultural innovation, value chain

1. Introduction

With growing awareness of global environmental problems caused by agricultural production, producers and retailers increasingly strive to introduce sustainability led changes at farm level. From a consumer-oriented perspective, the willingness to pay for sustainable production of food has increased in Europe over the recent years (de-Magistris & Gracia 2016; Vecchio & Annunziata 2015). This development fuels the legitimate expectation that sustainability led changes in agricultural production can contribute to the development of new opportunity recognitions and entrepreneurship by finding new ways of production and creatively developing alternative markets.

Previous studies in ecological economics suggest that competitive advantage in changing environments is determined by employing dynamic and entrepreneurial capabilities rather than by valuable, rare or inimitable resources (Newbert 2007; Alvarez & Busenitz 2001; Porter 1985). An assessment of resources combinations for responsible innovations in small and medium enterprises calls for new business models that source from collaboration in multi-actor networks (Halme & Korpela 2013). A propagation of cooperative approaches in recent years has led to a diversity of agriculture-based niche developments worldwide with multiple but small-scale effects on sustainable land management (e.g. Little et al. 2010). The potential for a broader impact is often inhibited by the failure to appropriate the value creation necessary for a long term establishment in the market. The development of new products is challenged by not reaching a competitive advantage over conventional management practices.

The overall objective of the study reported here was to assess the potentials and limitations of integrating sustainability assessment into innovation management processes. The question is addressed in the frame of a transdisciplinary project accompanying an ongoing innovation process for two case studies in north-eastern Germany. The first case aims at using surplus biomass for small-scale thermal production in wet grasslands. This will be enabled by a cooperative production strategy by pooling wet grassland farm area in the Biosphere Reserve Spree Woods/Błota in the federal state of Brandenburg. In the second case, smallholder farmers aim to realize the value of traditional quality breeds produced in a mixed poultry production system. This is explored through joint marketing of eggs and meat in Brandenburg and Berlin via Naturland Marketing, a trading farmer association for organic farmers. Semi-structured interviews were analysed based on network analysis, content analysis and case comparison in order to answer the following questions:

- What environmental, economic or social values are expected from the innovation as a contribution to sustainable land use?
- What is the potential and what are the limits of integrating sustainability assessment into innovation management processes in regard to value chain and territorial approaches?

1.1 Agro-ecological innovation

Agro-ecological initiatives born in the organic movement have the aim to extend the use of local resources as an alternative to the mainstream regime of industrialised agriculture (Barbier & Elzen 2012; Wezel et al. 2009). Activities often involve practices that call for low factor inputs per land unit, thereby favouring farm systems in regions with low yield potential or traditional cultivation practices.

The creation of alternative production practices as a new form of agriculture requires a comprehensive approach that differs for example from approaches of transforming conventional to organic farming by depending on multi-level and multi-actor cooperation to a larger extent, e.g. due to missing linkages with supply chains. Similar to processes of radical innovations, value realisation of innovative sustainable land management practices is challenged by quantity effects in implementation (economies of scale) as well as efficiency constraints in production and marketing. In regions, where value chains have adapted more or less completely to agricultural systems that follow the rules of economies of scale, alternative production systems find themselves in a situation where they are "too big to ignore, but too small to survive" (pers. comm. smallholder farmer). Positive impacts at a landscape level (spatial effects) then depend on coordinated and overlapping strategies between actors, e.g. in distribution and marketing. An improved linkage to supply chains (sector effects) depends e.g. on interaction of actors between sectors based on spatial proximity. Furthermore, an achievement of synergies as well as access rights to resources requires interaction between stakeholder groups previously unrelated in production practice. Termed system innovation (Elzen et al. 2004; Geels 2005), these type of innovations were found to encompass technological change by requiring a broad change process including adaptations in farm management, the production system or the business model as well as new combinations of resources allocations. Figure 1 illustrates the analytical framework for the assessment of farms that in order to develop new production processes are faced with constraints that can be partly explained by theories from small enterprise development (Glover et al. 2016, Porter 1985), and partly with theories from adoption of sustainable management practices (Schot & Geels 2008).

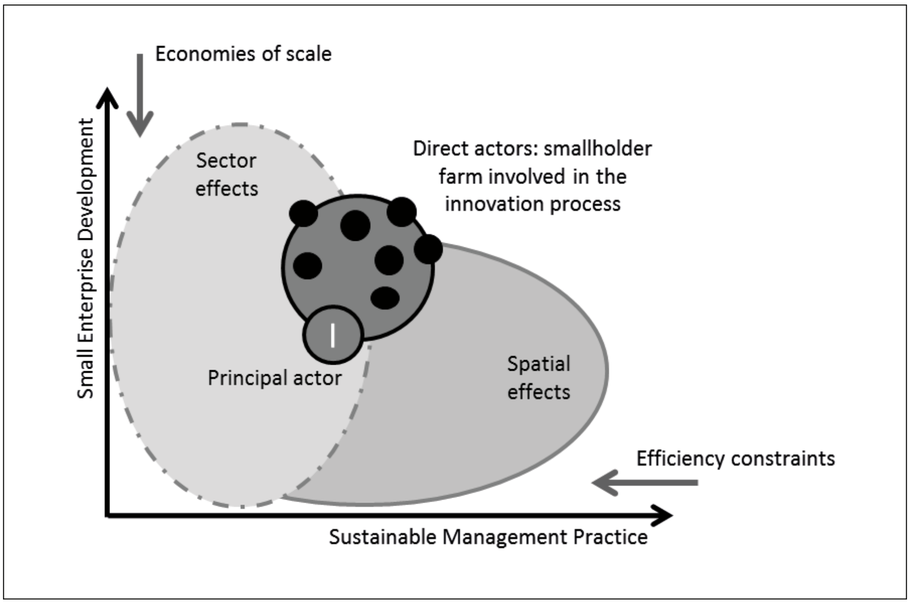

Fig. 1 Agro-ecological innovation systems influenced by economies of scale and efficiency constraints (own illustration).

1.2 Linking impacts at territorial and value chain scale

Traditional environmental impact assessment of production processes on farms generally targets spatial criteria. Units are based on ha of land, and impacts are often measured in emissions or effluents. Agro-ecological indicators for an optimization of integrated farming systems have been developed for example by Bockstaller et al. (1997). These indicators estimate the impact of cultivation practices on the environment, and enable farmers to adapt their cultivation practices to the requirements of an integrated farming system, from one cropping year to the next. Successive tools for assessing environmental, economic and social aspects of sustainable management practices in farming systems have differentiated between sustainability at farm-level and contributions to sustainable development at a regional scale (Ghadban et al. 2013).

Assessments in innovation processes on the other hand are often related to the value chain. Units are generally described per kg of product, such as in life cycle assessments (Lindner et al. 2010), while evaluations additionally put a strong focus on the stakeholders linked to the product (Sieber et al. 2015). An integration of the supply chain perspective and the production site with its natural environment remains a challenge due to trade-offs between the different characteristics of scope (Schader et al. 2014).

2. Method

The study of agriculture based innovations for sustainable land use was conducted in north-eastern Germany in a range of up to 300 km from Berlin. Economic activity declines with distance from Berlin, and the main area is characterised by agriculture, coal mining, renewable energies, and increasingly tourism. Agricultural practice is dominated by large farm enterprises with an average size of 238 ha, which is four times the German average. Grain, field forage and oil seed make up relevant crops in terms of land use. In light of current price developments, farms on marginal areas face increasing challenges to operate profitably in the long term. The overall development calls for economically viable alternatives based on innovative approaches. Often these are developed in a niche market environment, for example by making use of a demand for local, organic or high-quality products in the urban environment of Berlin.

The integration of two ongoing innovation management processes into a transdisciplinary research project on sustainable land use was the starting point of the analysis. The innovation in both cases was a combination of a product based on a new type of production process that is perceived as sustainable, and an organizational innovation based on a new form of cooperation between actors. In the first case, local farmers aim to explore the use of surplus biomass for small-scale thermal production in wet grasslands by implementing a joint strategy enabled by pooling smallholder farm land. In the second case, smallholder farmers in the poultry sector cooperate with Naturland Marketing, a marketing platform for organic farmers, in order to realize the value of traditional quality breeds based on mixed poultry production systems.

The overall approach is defined by participatory action research, characterized by the joint solution-oriented collaboration between practitioners and researchers (Pelenc et al. 2015; Padilla & Filho 2012; McIntyre 2008). The aim was to facilitate the development of the innovation towards higher market relevance and to achieve long term establishment of the innovation outside its initial niche. The process was being driven by practitioners while the role of the researchers was to reflect, assess and consult during the process of development and adaptation. The study reported here was conducted as an intermediate step in developing tools for an assessment of innovations for sustainable land use.

2.1 Case comparison and datacollection

In both case studies, sustainable management practices were introduced that can be described in terms of innovative change. Both case studies stand out due to their setting and situation:

- The innovation process is based in the agricultural sector and is in a phase of a conceptual or actual proof-of-concept,
- The sustainable management practice implicates additional costs that require compensation. The break-even threshold was not reached at individual farm level, mainly because additional benefits were not acknowledged by consumers. This component, however, was not clearly defined by the stakeholders at the outset of this study.
- The stakeholders were not aware of benchmark figures, instruments for resources planning or tools for integrated assessments such as RISE (Grenz 2013) or SMART (Schader et al. 2016). A production process “as is” has either phased out or did not exist from the start. In consequence, we found that the actors themselves employed no heuristic instruments for a quantified assessment of resources, outcomes or impacts e.g. based on book-keeping data.

Two main data collection methods were applied in the study, namely key informant interviews and focus group discussions. For each case study we conducted an on-site inspection together with actors involved in the innovation process followed by a transdisciplinary focus group workshop with experts from practice, and a workshop for reflection with researchers from different fields of sustainability science. Open-ended interviews were conducted with people linked to the innovation as well as additional stakeholders from each sectoral and regional surrounding. The interviews were taped and transcribed. Focus group discussions and excursions were documented by protocols and used additionally to understand interactions and relationships between actors. Data was analysed by content analysis and case comparison to identify the value perceptions of actors linked to the innovation.

2.2 Key informant interviews

Semi-structured interviews with open questions were conducted for both case studies. In regard to sustainability value perceptions, a response to questions can differ between open and closed questions. The question: "What do you associate with sustainability?" posed as an open question will often be responded to by an individual interpretation of the concept of sustainability, while a closed question may lead to socially expected responses.

Actors for the interviews were identified by their proximity to the innovation process via network analysis. Actors were categorised at three different levels of cooperation (Table 1):

A **principal actor** was identified who is closely linked to the idea or invention. The principal actor was characterized by the ability to recognize an entrepreneurial opportunity and initiate the process of combining and organizing resources. In both case studies, this person was not a farmer. The exploitation of the entrepreneurial potential, however, was strongly dependent on the commitment of a collective group of farmers who committed to the idea for implementation.

The group of smallholder farmers committed to the innovation process was identified as the group of **direct actors.** The direct actors brought own resources into the innovation process. The relationship to the principal actor is one of mutual dependence and joint ownership of the innovation process. The relationship between the principal actor and the group of direct actors is characterized by negotiation processes mainly aimed at improving the product or the production process.

The third group was termed **indirect actors**. This group was linked to the invention by loose ties in the sense that there was no engagement in the innovation process with own capital resources. Interaction with this group of actors, however, was seen as vital for success in the respective sector and region. Moreover, this group can be positively or negatively impacted by implementation, for example as a final beneficiary of improved regional assets for tourism or better quality products. The direct and indirect actors felt committed to the innovation process on the basis of regional proximity in case study 1, and sector proximity in case study 2.

2.3 Content analysis

Content analysis was applied to all transcribed interviews in order to understand the objectives associated with sustainable development by the actors involved in the innovation process. The concept was based on the understanding that value perceptions have an effect on resource allocations and decision making for example in ecosystem services assessments (MEA 2005), and thus should be recognised in innovation management, particularly when it comes to economic analysis. It was also used in order to reduce complexity by identifying the relevant objectives that linked the innovation process to concepts of sustainability.

Aligned with the overall participatory approach in the project, the content analysis was applied as an empirical method for qualitative and inductive research (Elo & Kingäs 2007). Whole sentences were coded, based on attributes of value perception and indicated by words such as "relevant", "important", "prior", "it is about", "essential", "crucial"). The open codings were grouped under higher order headings according to similarity. 15 interviews were analysed for Case Study 1 and 13 interviews for Case Study 2.

In a first step, 46 sub-criteria were identified and classified into 15 generic criteria used to explain the sustainability aspects of the innovation. The criteria were cross-checked against the three pillar approach of social, economic and environmental criteria. In a second step, three main categories were retrieved from further abstraction of sustainability objectives that ran across social, environmental and economic criteria.

Table 1 Description of actor relationships in the case studies.

	Principal actor	Direct actors	Indirect actors
Case study 1: **Small scale thermal energy production**	UNESCO Biosphere Reserve Spree Woods, State Office for Environment	10 smallholder farmers with joint land ownership of 1000 ha in the Spree Woods/Błota	Tourism Nature conservation Hunters and fishermen
Case study 2: **Mixed poultry production**	Naturland Marketing GmbH	8 farmers with total poultry production of 3000 hens produced and marketed in cooperation with Naturland	Processors (meat) Extension services Breeders Marketing organisations

3. Results

The principal, direct and indirect actors involved in the innovation process had a clear idea of the values expected from the innovation in regard to sustainable development. The criteria formulated in each case study differed in minor points at the level of sub-criteria, while at the levels of higher abstraction all criteria were considered relevant by the actors in both case studies. An attribution of criteria to social, economic and environmental aspects showed that the range of criteria equally covered all three dimensions of sustainable development (Table 2). In the following, the main differences between case studies are described, and an example is presented for each of the three main objectives identified, namely local added value, closed circular systems and capacities for development. Details of the content analysis are presented in Table 3.

3.1 Expectations of the stakeholders in regard to sustainability

The component of remuneration and compensation in financial terms was termed a natural objective of the innovation process by almost all interviewed actors. One main concern was the difficulty to reach long-term market establishment in spite of the self-imposed constraint by committing to small-scale production.

The interviewed actors were fully aware of the fact that eggs, meat and biomass held little potential for a unique selling proposition as long as the additional benefit of the production system was not made explicit. The main product asset articulated in case study 1 was to achieve local effects by offering the extra service of "keeping the landscape open" in order to preserve a cultural landscape with a distinct esthetic value and biodiversity. This was considered relevant for the local communities in the region of the biosphere reserve, and furthermore, a requirement for the survival of the region as a tourist destination. In case study 2, the main product asset was seen in "ethical production" that involved raising equal numbers of male and female chicken in order to avoid premature slaughter, improved animal welfare such as small herds held in free-range husbandry as well as a general support of smallholder farming systems.

Criteria of diversification in farm structure were considered more relevant by case study 2, next to ethical issues. The actors took pride in achieving non-standardised production processes, in the sense that every farm was encouraged to pan out how the requirements of the production process would fit best to the local circumstances of the farm. Therefore, the notion of developing alternative approaches, "other" or "better" than existing organic or conventional farming practices were considered basic criteria of sustainability.

Contrary to this, consensual decision making was articulated only by case study 1, due to a strong sense of accountability for land development. This was underlined by a strong recognition of land ownership in the present generation as well as for future generations in terms of farm succession and community stability. The notion of preservation of farm structures and land as is were considered elementary criteria of sustainability that were not mentioned by case study 2.

3.2 Local added value

Local added value was defined as feedback effects expected from the implementation of the innovation in the immediate surroundings, implying financial, social and environmental benefits. "Local" was understood in reference to the unit of observation. The direct actors mainly referred to the farm in a village environment, or the village in the district environment, while indirect actors and principal actors referred to the district, the region or the federal state.

Benefits included financial returns for people working in adjacent sectors considered sensitive or worth protecting in the region, such as tourism in case study 1, and food processing in rural agricultural regions in case study 2. The expectation was that the implementation of the agro-ecological production processes would achieve additional income sources and indirectly contribute to the survival of small scale farmers, but also producers and processors.

3.3 Closed circular systems

The notion of closed circular systems was defined in a broader context encompassing a balanced nutrient flow in order to include an efficient use of natural resources with no surplus or unutilized waste production and recycling of materials. Furthermore, closed cycles were also understood in social terms in the sense of well-functioning networks for cooperation within the sector or region.

The aspect of closed cycles was often linked to regional anchorage, but was also extended to the meaning of exploiting the full value chain by coupling elements needed for production and marketing independent of distance. For example, in the case of mixed poultry production, the smallholder farmers had calculated that for approximately every 180 eggs produced, one stock chicken was raised. The reduction of surplus production in this case included the objective of a balanced supply and demand for example by good customer relations. In case study 1, the exploitation of previously underused biomass was considered the major element for closing perceived gaps in the functioning of local social structures and local monetary flow.

3.4 Capacities for development

Although conscious of the constraints of small-scale production, a strong expectation of growth potentials was communicated in the interviews. Capacities for development were defined as a potential to develop the innovation along horizontal lines, such as replicating the production process in other regions by including more smallholder farmers into the programme, but also along vertical linkages, for example by the ability to address marketing structures outside the organic sector. Actors in both case studies referred to capacities based on diversification and de-centralization, but also communication and knowledge transfer.

Table 2 Social, economic and environmental criteria for sustainable agro-ecological innovation.

Criteria	Sub-Criteria	Social	Eco-nomic	Environ-mental
Economic efficiency	a) full cost recovery of costs and inputs, b) achievement of net profit, c) achievement of a competitive market position.		x	
Product demand	a) acknowledgement of product criteria, b) purchase of the product, c) willingness to pay a surcharge, d) regular purchase.		x	
Integrated production	Best practice in terms of a) farming practice, b) resources efficiency.	x	x	x
Employment	Production and marketing generate a) new sources of income, b) new options for employment.	x		x
Growth	Production and marketing a) implemented according to expectation, b) improved via horizontal linkages, c) improved via vertical linkages, d) transferred to the next generation (future ability).		x	
Continuity	Quality and quantity of production is a) stable and permanent, b) assured against risks, c) secured by ownership and property rights, d) contributing to the environment and livelihood of the region.	x	x	x
Regionality	Production and marketing rely on a) integration of local actors, b) integration of local resources, c) generation of local benefits.	x	x	x
Cooperation	Production and marketing lead to a) communication and interaction with actors along the value chain, b) joint activities with other actors for mutual benefit, c) merging of activities between actors along the value chain, d) collaborative decision making.	x		
Circular material flow	Production and marketing support a) recycling of resources and materials, b) closed cycle of goods and products, c) diversification of assets and risks.	x	x	x
Quality	Production and marketing meet the requirements of the consumer in regard to a) taste and esthetic perception, b) state of condition and shelf life, c) general standards defined by market and trade, d) criteria extra to common standards.	x	x	
Diversification	Production and marketing are based on a) non-standardised farm size and structure, b) non-standardised production processes, c) diverse and inclusive staff structure, d) alternative approaches in product handling, e) improvement of existing approaches in product handling.	x	x	
Independence	Production and marketing approaches can be decided and implemented independent of actors along the value chain.	x		
Biodiversity	Production and marketing do not negatively impact the conservation of a) species, b) genetic resources, c) habitats.			x
Climate	Production and marketing comply with best practice in climate relevant emissions.			x
Ethical aspects	Production and marketing comply with a) ethical production standards, b) reduction of waste, non-renewable resources and surplus produce, c) reduction of input resources beyond the necessary (e.g. large packaging).			x

Table 3 Main objectives associated with the agro-ecological innovation as perceived by the actors involved in the innovation process.

Main objectives	Small scale thermal production (Case study 1)	Mixed poultry production (Case study 2)	Criteria
Local added value	The key formula was not organic farming, but „grown here, produced here, processed here, and exploited by the local people (SP1). In consequence, financial returns will flow back to the producers and into the region via tourism. (SP2). It can contribute to the diversification of income sources. (SP3). It can generate financial returns that should be available for those who work in those farm areas. (SP6). The use of biomass requires technical resources; logistical questions need to be addressed. I need partners with land, entrepreneurs with financial backup who have the capacity to join in. The kind of information we need is: we have sold so much honey, and we have won ten new bee keepers. They will survive because of these activities. (SP17) And then the value chain is set. Not for mass production, but in the sense of an honest regional product. (SP22).	What we see as a basic element is the potential for the region: buying feed in Germany, breeding of animals in the region. That eggs will be marketed in the region. As well as the meat. (EC1). We say, organic farming is sustainable, so what do we do on top? The regional location of slaughter and marketing are on top. (EC3). The principles of Naturland define organic farming as „a contribution to the conservation of the natural resources and livelihood. This includes biodiversity, climate conservation and animal welfare". For smallholder farmers it pays off to set up mixed poultry production as an additional income source. This is relevant in order to convince the farmers that mixed poultry is not only more work, but pays off financially. (EC4). When we start a project like this, it is all about the creation of jobs, continuity and keeping people employed, starting from the work in the stall, the care for the animals down to the packing of eggs. (EC16).	Economic efficiency Employment Regionality Independence Biodiversity Climate
Closed circular systems	Practically joining circular systems. To be able to say: "we have this area with surplus biomass, but we can save costs by exploiting the energy in situ by coupling cycles". The local benefit will increase manifold when we achieve a coupling of local cycles. It means we can generate value and keep jobs in the region. (SP1) From the narrow perspective of nature conservation only two things are relevant: 1) taking out plant nutrient matter, 2) making sure, the meadows have enough moisture. What happens with the biomass is next to irrelevant. (SP4). And that is it, overall, that we come to the point where we have closed regional cycles that may be able to continue to other levels. Then we will have a true innovation, specific for this location. (SP17).	I would define sustainable land use as linkage with all adjacent elements. Socially, this is the village, the surrounding, the region. Environmentally, I see the in- and output in agriculture, and in terms of marketing, it is a closed value chain in the near region. (EC1). We need closed cycles in organic farming. If we now had someone innovative in processing, someone who uses surplus meat in food processing, we'd be even better set. (EC2). All chicks are raised. Wonderful. (EC3). For every 180 eggs one chicken must be eaten. The information is that this project will survive only, when the meat is eaten. The customers need to have this information. (EC7). I liked the idea. We wanted to keep poultry. And we also needed the manure. The circular system is very important. So we thought, this is a good thing, so we set up this type of poultry production. (EC14).	Product demand Integrated production Circular material flow Ethical aspects
Capacities for development	We could make it bigger and broader. The destination of this innovation is more than just the Spree Woods. The aspect of decentralization is the actual approach where I see the potential innovation. (SP1). Where we slowly and carefully have to see to the formation of other small networks. The Biosphere Reserve must become one of several performers. (SP2).	I think it is relevant to look at marketing structures outside of organic trade. Our idea is to get out of the niche. (EC1). In my opinion, this produce will always be a niche for few smallholders. But I imagine that it can be transferred to other regions. (EC3). We implement what we think is the right idea. We get experience and try to grow. We would like to come to the point where we can say we have a project that can be communicated broadly, so that we win more farmers who set up more mixed poultry production sites. (EC14).	Growth Continuity Cooperation Quality Diversification

Interviews were coded SPx for Spree Woods/Błota, and ECx for Naturland Marketing.

4. Discussion

Innovations, according to the actors involved in the innovation process, are considered sustainable when they a) achieve local beneficiary effects for as many people as possible, b) contribute to closed cycles in production and marketing, and c) improve the capacity for horizontal and vertical development. The combined effect is perceived as an additional asset extra to local, organic or conventional smallholder production by the actors.

All three main objectives for an agro-ecological innovation illustrate the relevance of local anchorage. For agrifood systems, localized production systems have been analysed based on the systemic nature of relationships maintained by actors who jointly shape a territory through cooperation and joint products (Torré & Wallet 2013). Spatial differentiation, cooperation and bottom-up development are linked with this approach. The results from this study add elements of regional autarky. In the case studies this becomes evident by the actors expectation to exceed the regular requirements for common organic agricultural production, e.g. of Naturland Marketing (Naturland 2015) and to gain independence from mainstream sector relationships.

4.1 Making explicit societal and environmental value creation

In both cases, the innovative approach for agro-ecological production exceeds the regular requirements for organic agricultural production. Thus, the production is affected by a self-restriction to produce low quantities and therefore consciously refuse to use economies of scale. Consumers, however, are mainly unaware of these extra efforts for sustainable land use. At the same time, the actors cannot benchmark their activities against common requirements such as a product label or standard based on common farm statistics. An assessment of sustainability objectives during the innovation process can support the actors in articulating the benefits of the agro-ecological innovation, particularly at the level of the principal actor who takes the role of the entrepreneur. An entrepreneur is characterized by typically facing high ambiguity and uncertainty in the pursuit of a new venture. Decision making is largely built on individual heuristics and beliefs, while factual-based logic may be either too overwhelming or not available where an innovation is created (Alvarez & Busenitz 2001). While the particular benefits of the agro-ecological innovation were not clearly defined at the outset of the study, the actors could harmonize their target and product criteria during the course of the study. The result was perceived as a basis for advancing marketing measures, customer relationships as well as communication between actors.

4.2 Plausibility and applicability of the approach

Local added value, closed circular systems and capacities for development are found to link both territorial and value chain approaches. The innovation is considered successful by the actors when the additional product assets are achieved and financed by revenues. One specific of the innovations analysed here is the dependency of success on the willingness of a group of farmers who commits to implementing the innovation in joint cooperation. Case study 1 requires a minimum number of farmers to achieve the aim of open landscape conservation. In case study 2, a critical amount of eggs and meat is indispensable to target the market.

All three main objectives have a clear resonance with value chain assessments for example in supporting linkages with other actors along the value chain, upgrading returns from production and generating financial flows that become an integral part of the region and sector involved (e.g. Graef et al. 2014; Kaplinsky & Morris 2001). The application of the criteria is strongly actor-oriented. This can be a detriment when it comes to an assessment of site-related environmental impacts. While the criteria showed a comprehensive approach in addressing the sustainable and efficient practices needed for transformation towards sustainable development, environmental criteria were selected to a lesser extent by the actors.

5. Conclusion

The study was conducted as an intermediate step in developing assessment tools for sustainable agro-ecological innovations in a smallholder farm environment. The integration of sustainability assessment in innovation management was found useful particularly by the principal actors, namely the biosphere reserve management and Naturland Marketing. The benefit is seen in the clarification of objectives in management, and in communication with direct and indirect actors. The criteria were grouped along three main objectives that encompass both value chain and territorial approaches as well as social, economic and environmental values. The results indicate possible development pathways for an assessment tool that supports the actors in innovation management with the aim of improving capabilities for long-term market establishment and sustainable land management, e.g. via life-cycle assessment or balancing methods. The tool, however, must implicitly ensure equal consideration of environmental impacts next to social and economic impacts, as these were considered to a lower extent by the interviewed actors.

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SECTION II

Section II analyses the organisational level of an innovation process in the Triple Helix System of Innovation for Sustainability (THIS), thereby presenting two case studies at this level.

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A framework for structuring interdisciplinary research management

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ABSTRACT

With project-based research becoming a major form of research organisation, coordination and management has become an important task in interdisciplinary research collaborations and a key determinant of their success. Yet little theory-based information is available regarding the decisive determinants of project management success and the functions it needs to fulfil. Based on the assumption that such projects are temporary organisations, we have adapted the Competing Values Framework (Quinn, 1988; Quinn and Rohrbaugh, 1983), taken from the literature on organisation management, making it usable for project managers in interdisciplinary research projects. Via a case study from a European Integrated Project, we have developed four essential management fields, relating them to the existing literature on management of inter- and transdisciplinary research projects. Our resulting Interdisciplinary Research Management Framework makes coordinator functions explicit and plausible, while also being generic, in that specific coordination duties can be attributed to functions relatively independent of project topic. The framework can facilitate the structured planning, conducting and evaluating of management activities for large interdisciplinary projects. It can be a practical tool for project leaders and scientific administrators, but may also help to facilitate further academic discussion on interdisciplinary research management. The production of results dependent on information transfers between project consortia and target arenas (e.g. the science–policy interface) remains a major challenge. In any case, a "re-invention of the wheel" process, in the sense of personal and project-specific learning, still seems to be somewhat necessary for organising context-specific, temporary interdisciplinary research programmes.

1. Introduction

It is commonly expected that applied environmental research should contribute towards solving the grand challenges of our environment, such as sustainable land use, food security or conservation of nature (e.g. Kueffer and Hirsch Hadorn, 2008). The complexity, ambiguity and uncertainty of such challenges require analysis from many different viewpoints and disciplines in ways that are best addressed by inter- or even transdisciplinary research approaches (Jahn, 2008, p. 35). In addition, crossing disciplinary boundaries in addressing a common research goal often also involves non-academics (for a review on terminology, see Tress et al., 2004; for interdisciplinarity indicators see Huutoniemi et al., 2009). Such complex inter- and transdisciplinary research processes require coordinated research management to be successful and efficient (Pregerning, 2006), but documented practical knowledge in this area is scarce (Dewulf et al., 2009).

The design of an inter- or transdisciplinary research programme aims at achieving a holistic, comprehensive picture of the problem at stake (Klein, 2004), requiring an open and complex research design. This, however, usually comes into conflict with achieving effective organisation and management, because it is confronted with various attitudes of researchers from different disciplines and different languages and cognitive systems (Pregerning, 2006; Hollaender et al., 2008; Tress et al., 2004). Evaluations of experience gained in inter- and transdisciplinary research settings have resulted in general management rules and recommendations, such as facilitating mutual learning, enabling shared goal definition, creating rules for cooperation and synergy, managing complexity and heterogeneity, planning integration, balancing personal attitudes of involved researchers, endorsing publications in refereed journals, and considering project impacts on career opportunities (see Hollaender et al., 2008, p. 385; Tress et al., 2005; Bruce et al., 2004; Bergmann et al., 2005; Kueffer et al., 2007).

It is recognised that the situation-specific circumstances of interdisciplinary research are important determinants of success or failure and that it is, therefore, difficult to generalise rules for effective management (Hollaender et al., 2008, p. 387). Moreover, a theoretical framework for interdisciplinary research from which viable solutions for research management could be drawn

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is lacking (Pickett et al., 1999). According to Aubry et al. (2007, p.328), general project management literature lacks both the theoretical foundations and valid empirical models needed to satisfactorily master this challenge. Hence, project managers often follow the "learning by doing" principle, which may unfortunately lead to a "re-inventing the wheel" phenomenon, frequently experienced by researchers involved in inter- and transdisciplinary research projects (Tress et al., 2007). A more precise description of functions to be fulfilled by project managers could reduce this time-consuming learning process and, thereby, increase interdisciplinary research management effectiveness. Bergmann and Schramm (2008, pp. 9–10) point to the need for a sciences-led discussion about determinants of good inter- and transdisciplinary practice and suggest the debate should spotlight instrument improvements, knowledge integration methods and project management tasks.

Hollaender et al. (2008), Dewulf et al. (2009) and Kueffer and Hirsch Hadorn (2008) have discussed management principles for inter- and transdisciplinary research. Hollaender et al. (2008, p. 395) suggest applying "adaptive management based on regular self-reflection and re-adjustment of the research process". Dewulf et al. (2009) describe the application of different methods of "adaptive management" to facilitate creation of a shared conceptual framework in inter- and transdisciplinary research on water management. While this is oriented towards project-internal conceptual coherence, Kueffer and Hirsch Hadorn (2008) postulate that "boundary management", meaning stakeholder deliberation in framing adequate research questions for effective problem solving, is crucial. They argue that "such research may assist problem-solving in three ways, by analysing causal relationships (systems knowledge), clarifying conflicts of interests and values (target knowledge), or contributing to the development of appropriate means for action (transformation knowledge)" (Kueffer and Hirsch Hadorn, 2008, p. 1, for definition of knowledge produced by inter- and transdisciplinary research, see Hirsch Hadorn et al., 2008, p. 31). Pennington (2008) proposes the principles of Maslow's hierarchy of needs, constructivism, and organisational learning as coordination means to facilitate initial mutual learning in the early phase of interdisciplinary collaboration. Quinn (1988, Quinn and Rohrbaugh, 1983) has developed the Competing Values Framework, for effective organisational management based on empirical results, which has been proved to be useful and valid in various management fields, but has not been considered in the field of interdisciplinary management yet. This framework will be discussed in more detail in the next section.

Research is increasingly being organised into temporary limited and externally funded projects. This project based work organisation follows a similar development evident in business organisations, where projects have evolved as managerial structures to address strategic and innovative aims since the 1990s (see the concept of organisational management of Aubry et al., 2007). While the above-described investigations of interdisciplinary research management have to a large extent addressed important shortcomings in integrating research, including the achievement of viable solutions, there is as yet no concept for solving the practical problems of interdisciplinary research management in temporary research projects. These would include both the introspective side of management, looking at the internal coordination of tasks and partners in collaboration, as well as that of management looking outward towards external expectations and needs (Hollaender et al., 2008, p. 387). Furthermore, according to Pickett et al. (1999), these would also include the systematic development of a shared conceptual framework over time, via reflection upon and re-adjustment of the research process, concerning necessary outputs, outcomes and channels of communication.

The objective of this paper is to develop a framework for addressing the needs of temporarily organised interdisciplinary research management, derived from reflection on a particular case study in light of the Competing Values Framework, itself originating from the entrepreneurial organisation management literature (Quinn, 1988; Quinn and Rohrbaugh, 1983). Our results are meant to improve interdisciplinary research management effectiveness and increase the learning effects available from the existing interdisciplinary management literature. In order to structure learning processes in interdisciplinary research projects, this framework can offer support for research project managers in the planning of resources, the management of numerous functions during a project's lifetime and the integration of results. Furthermore, we intend to improve understanding of interdisciplinary research management as a means for better-informed discussion of future research agenda setting, scientific administration, project management and science–policy.

The paper first describes the methodological approach for developing this framework in Section 2. Section 3 then describes the adapted framework derived from our research. In Section 4, we discuss the results of our research, while Section 5 is dedicated to discussing conclusions and some implications of our results.

2. Materials and methods

2.1. The Competing Values Framework

The Competing Values Framework (Quinn, 1988; Quinn and Rohrbaugh, 1983) was developed out of a series of empirical investigations by Quinn in order to detect factors influencing organisational effectiveness. It served originally to orient organisation leaders regarding the roles they are expected to fulfil. The original development of the framework had the intention of integrating many of the dimensions proposed by a variety of authors on effective organisational management (Cameron and Quinn, 2006, p. 33); in the process, the Competing Values Framework went beyond the listing of success factors or indicators, which usually provide only limited practical orientation to management (Nicolai and Kieser, 2002; Aubry et al., 2007).

From his investigations, Quinn found that organisational effectiveness is characterised by two seemingly contradictory values: organisations should be adaptable and flexible while, at the same time, being stable and controlled. Hence, organisational leaders need to fulfil contradictory functions, as graphically shown in Fig. 1, where two axes represent the (a) internal and external domains and (b) the poles between differentiation and integration (decentralisation–centralisation). The axes form four quadrants in which indicators of organisational effectiveness can be meaningfully grouped while also representing seemingly conflicting values. Through this schematisation, Quinn increased comprehension of 39 indicators of organisational effectiveness and improved their practical applicability (for a summary of the method see Quinn, 1988; Cameron and Quinn, 2006). Quinn's original framework (Fig. 1) has four quadrants representing four dimensions of management and core competing values: (1) human relations (e.g. organisational culture), (2) rational goals (e.g. products, market share), (3) open systems (e.g. idea generation, information uptake) and (4) internal processes (e.g. controlling, information management).

The Competing Values Framework can be seen as a plausible frame of reference for the management needs of inter- and transdisciplinary research in time-limited projects which, like the management of temporary projects in business or non-profit organisations, require the fulfilment of different roles or functions at different working levels (see e.g. Kieser and Ebers, 2006). In both

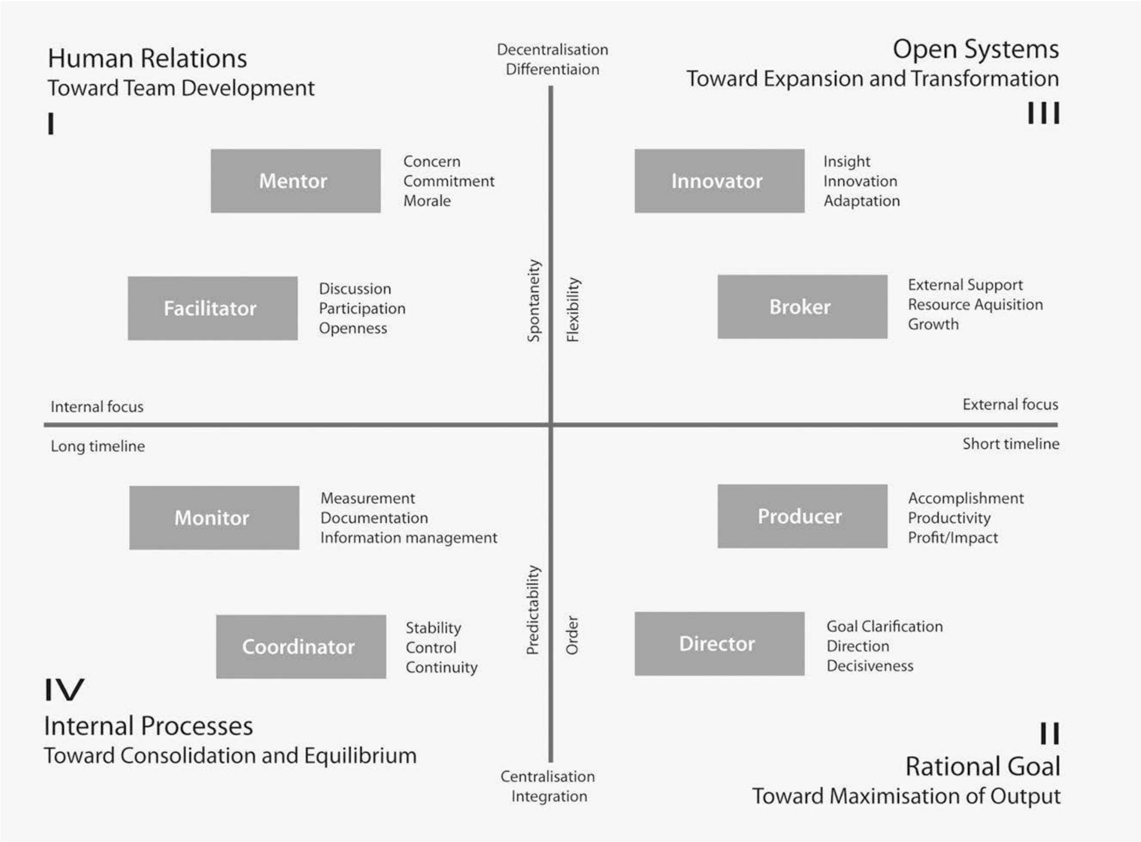

Fig. 1. The Competing Values Framework (Quinn, 1988).

cases, there is a need for setting up a structure and defining a process that can help the organisation to achieve its intended goals (Kieser and Ebers, 2006; W.K. Kellogg Foundation, 2001). While interdisciplinary research projects are embedded in scientific structures and value systems, they also operate as flexible organisations that work towards maximising output.

Examples of testing and application of the CPF are Zafft et al. (2009) on measuring leadership in self-organised student teams, Übius and Alas (2009) on organisational culture types in the electronics industry in different countries, Miyashita and Nakamori (2007) on functions of science–policy intermediaries or Lamond (2003) on testing the validity of the CPF for Australian organisations. Interdisciplinary scholars have discussed integrated research in light of organisational management literature. We refer to Mogalle (2001), who adapted a concept from organisation management to help reflect upon the management of transdisciplinary research. Of the various authors who describe the different roles coordinators of interdisciplinary projects need to fulfil, and thereby point to the need for organisational structure, two are noteworthy for our purposes. Kilburn (1990) distinguishes the "paymaster", the "organiser" and the "doer", who, if trustfully and fairly working together, are able to solve a particular novel problem. Saretzki (2005) proposes understanding technology risk assessment as an analytical-deliberative process and, in doing so, distinguishes two kinds of experts: *disciplinary experts*, who provide knowledge concerning particular technologies, and *Technology Assessment experts*, who participate in both analytical (knowledge integration) as well as knowledge processes (intermediation of the research process and knowledge created for science, policy and public domains). Although their work has covered important aspects of management, these authors unfortunately do not provide project managers with practical advice nor an overview of how to organise and structure such organisations. We propose that a modified version of the Competing Values Framework can help in pursuing a functional approach towards fulfilling temporary interdisciplinary project management needs in a logical, consistent and generalisable way.

2.2. *The SENSOR case study*

An example of increasing need for interdisciplinary research management can be found in the field of sustainability impact assessment as an emerging concept for policy support, involving the development of instruments and tools that seek to provide scientific evidence for policy decision making. Research conducted for such impact assessment is arguably one of the currently most illustrative examples of interdisciplinary research, especially where achieving a balanced assessment of environmental, social and economic impacts is taken seriously. In Europe, the political requirements for knowledge-based policy making are laid down in the European Commission's Impact Assessment guidelines (CEC, 2005, 2009a). In the context of supporting practical implementation of these guidelines, the Directorate General Research launched a call for provision of ex ante Sustainability Impact Assessment Tools within the 6th Framework Programme (2002–2006), under the sub-priority "global change and ecosystems".

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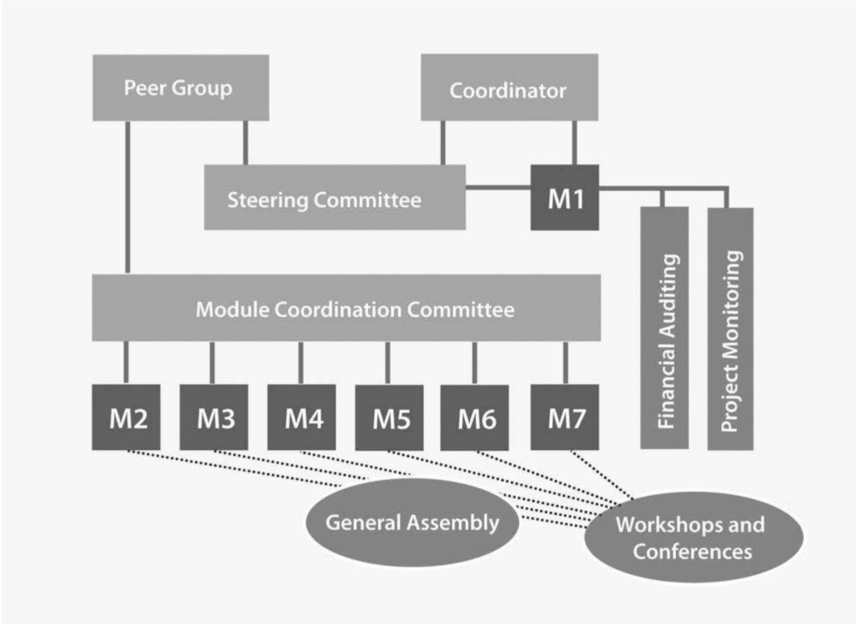

Fig. 2. The SENSOR management structure (M: Module with M1: Scientific coordination and analytical framework; M2: European land use scenario assessment and forecasting; M3: Regional sustainability problems, risks and thresholds; M5: Data and indicator management; M6: Sustainability issues in sensitive regions; and M7: Stakeholder participation and institutional analysis).

SENSOR (Sustainability Impact Assessment: Tools for Environmental, Social and Economic Effects of Multifunctional Land Use in European Regions) belonged to a first generation of EU-funded Integrated Projects in the 6th Framework Programme of the European Commission. Funded for four and a half years, it was set up to bring together a critical mass of European researchers for obtaining "specific results relevant to addressing major societal needs. These projects received high contributions from the EC and raised high expectations regarding their potentially significant impacts" (CEC, 2009, p.18).

The research undertaken within SENSOR sought to develop Sustainability Impact Assessment Tools for environmental, social and economic effects of multifunctional land use in European regions, and it has been evaluated as one of the most important projects in the domain of tools for sustainable development (CEC, 2009b).[1]

The project team involved not only several scientific disciplines from environmental, social, economic and land use sciences, but also researchers from 15 countries across Europe. The team was further enlarged midway by including researchers from Brazil, China, Argentina and Uruguay to test the transferability of the approach to non-European conditions. In total, about 100 researchers were involved.

The project had to be "product oriented": not in the commercial sense, but rather in developing what the EU called "specific results" to be used by practitioners and administrators in impact assessment processes. The aim was not primarily to produce new knowledge, but rather to integrate a diversity of pre-existing types of knowledge into a usable tool (De Smedt, 2011).

This requirement entailed two tasks: (i) interaction with the user community of the envisaged product from early projects stages on, to ensure product usefulness, and (ii) integration of all research tasks of all project partners into the research product development process.

A set of management instruments for operational planning, communication, monitoring, reporting and dissemination was set up at the beginning of the project and adapted annually according to learning effects and project progress. Project management included the coordination of technical activities as well as the overall legal, contractual, ethical, financial and administrative management laid down in the guidelines for Integrated Project Management (CEC, 2003). Detailed management tasks were determined in the initial "Description of work" (SENSOR, 2004). The following two figures illustrate the management organisation (Fig. 2) and the technical organisation of research modules (Fig. 3).

Fig. 2 shows the organisational management structure of the SENSOR project. Seven modules were each structured around 2–4 work packages, overseen by each of the module's coordinators. In the SENSOR case, modules are thematic and project-specific management substructures, again detailed in thematic work-packages with research goals, responsibilities, milestones and deliverables. Modules involved 5–30 researchers in thematic teams and work-package sub-teams. Due to the integrative nature of the project, some researchers and research-institution teams were part of more than one module knowledge production took place in Modules 2–7, with each being broken down into several work packages. Both work packages and modules were assigned to a coordinator drawn from the consortium. This "interdisciplinary hierarchy" had to be coordinated such that interaction between the modules took place. Overall project management was undertaken by Module 1, which was also responsible for scientific coordination, conceptualisation, integration of results, financial auditing and project monitoring. The integration of the module's work was overseen and coordinated by the module coordination committee, which included the coordinators of Modules 2–7, later enlarged by Module 8. The project consortium was advised by an independent scientific peer group, comprised of eight experienced and widely recognised scientists representing complementary disciplinary backgrounds. A steering

[1] For details on the project's scientific approach and results, see Helming et al. (2011a,b) and the project website www.sensor-ip.eu.

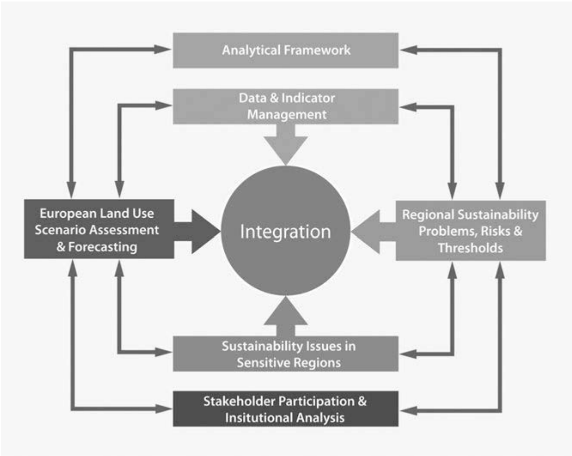

Fig. 3. The SENSOR module structure with scientific coordination & analytical framework = M1, European land use scenario assessment & forecasting = M2, Regional sustainability problems, risks & thresholds = M3, Data & indicator management = M5, Sustainability issues in sensitive regions = M6, Stakeholder participation & institutional analysis = M7.

committee, comprised of the directors of the three largest project partners, including the overall project coordinator, consulted on strategic planning and conflict management issues. The peer group and the steering committee attended annual project meetings and were also consulted periodically for review, reflection and advice. Strategic decisions were communicated once a year via a general assembly consisting of one representative from each partner institute. Responsibilities of all management levels were laid down in a Consortium Agreement, signed by each contracted party at the beginning of the project.

Fig. 3 illustrates the integrative managerial approach of the SENSOR research strategy. All modules produced context-specific knowledge at three scales (European, regional, and local), which was related to the work of other modules and had to be harmonised in order to be integrated into the final product. While conceptualisation of the integration process was overseen by Module 1 (Scientific coordination and analytical framework), its practical implementation was conducted by setting up a computer-based modelling tool, overseen by Module 4 (Integration of Sustainability Impact Assessment Tool: SIAT). Development of the concept and implementation of the logic for assessing policy impacts on land use required quite a large amount of facilitated communication between all project interfaces. These consisted of, on the one hand, the science–policy and science–stakeholder interfaces that made up the external target arena for project products and, on the other hand, the many internal meetings and workshops within and between the working modules.

Coordination challenges for interdisciplinary research management have been criticised already in general, e.g. the dependence of external conditions or the effort expended for relatively unspecified outputs in inter- and transdisciplinary research (see Bergmann and Schramm, 2008, p. 7). Also, for this kind of EU projects, specific external challenges have been named. The EC contribution to the projects included funding for coordination in order to reduce the Commission's in-house costs (Rietschel et al., 2009) and especially large consortia involved have been evaluated very critically with regard to greater management challenges (Marimon et al., 2004): namely, the complexity and investment involved faced by the project management; the high degree of responsibility for the coordinator; and risks associated with the project's long duration and commitment (CEC, 2004).

Fully aware of these general characteristics, and knowing that Integrated Projects (IPs) were not included in the 7th Framework Programme of the European Commission (EC), we chose SENSOR as the case study (see Yin, 2003; Krohn, 2008) for our analysis for several specific reasons:

- The size of the project and its research goals generated an exceptionally great need for iterative and interdisciplinary integration.
- The project has also been significant as a role model, from which acquired experience has been feeding into the design of current and future EU and national research programs.
- The project aimed at making pre-existing knowledge in a range of scientific fields usable for policy makers (De Smedt, 2011). The expectations were to achieve a goal, previously determined by policy makers; therefore putting the project within the range of organisational structures to which the Competing Values Framework is applicable.
- The project dealt with research for policy support, thereby addressing an emerging demand as expressed in strategic research plans.

2.3. Method

The work presented here is based on three kinds of analysis, forming the methodological basis for development of our overall framework: (1) content analysis of working documents and contracts (CEC, 2003), (2) team-reflected experience and documented action analysis and (3) review of the inter- and transdisciplinary management and organisation management literature.

The inclusion of documented action as experience (method 2) is necessary, because content analysis of documents is not by itself a sufficient method for describing how the contents of a document – here, the EC guidelines for Integrated Project management of 2003 – are actually implemented in practise (Prior, 2008, p. 485). The practical insight of the four authors having been members of the coordination team is additionally necessary to derive the intended results in order to improve interdisciplinary research management practise. This aspect of our method is somewhat similar to action research, where researchers typically gain data from their involvement in the process (Avison et al., 1999). Management action during the SENSOR project has been documented in meeting protocols, e-mails, deliverables, reports and notes.

In order for the Competing Values Framework to enable us to develop a comprehensive picture of interdisciplinary research management and to identify needs for adaptation, each of the three methods mentioned above was used to answer the following research questions:

1. What were the management tasks (1) as *prescribed* by the guidelines for project management (EC 2003), (2) as became *practically relevant* during the SENSOR project lifetime to develop expected results and products and (3) as *reported* by the literature on inter- and transdisciplinary management?
2. What activities were actually undertaken by the management to fulfil these tasks?
3. What can be derived from the experience gained for improved management based on the Competing Values Framework?

With the described methodological framework, we follow Cronin et al. (2008) in their general approach to analytic integration of different qualitative data sets. With the help of the three analytical methods, the Competing Values Framework was adapted to the specific needs of research management in team discussions. Where appropriate, we added or renamed functions to be fulfilled by interdisciplinary research project management to differentiate it from the original target of the Competing Values Framework for business organisation management. This paper is a result of a team-reflection process which was foreseen from the beginning of the project as a work package (for team discussions of data sets for analytical integration, see Cronin et al., 2008, p. 583).

The results of the adapted Interdisciplinary Research Management Framework are described in the next section.

3. Results

The following section provides an analysis of the S management experience in terms of adapting the Competing Values Framework (see Fig. 1) in order to better fit it for management of inter- and transdisciplinary projects. Fig. 4 illustrates the adaptation, our so called Interdisciplinary Research Management Framework with changes marked in grey.

3.1. Interdisciplinary culture

The first quadrant of Fig. 4 represents the management of internal communication and collaboration, which we see as the management of an interdisciplinary culture in the research team. The creation and maintenance of an interdisciplinary culture has been frequently reported to be a crucial success factor within projects (e.g. Pickett et al., 1999; Boix Mansilla and Gardner, 2003). As has been proposed by other authors (e.g. Wiesmann et al., 2008, p. 439), the development of an interdisciplinary culture is usually limited in that researchers foremost represent their (competing) home organisation and, therefore, may introduce conflicts into a project that are not related to its research questions. An external advisory group may help to reflect on and refocus such internal processes. Adler et al. (2009) conclude that research management needs to establish legitimacy for taking leadership. The SENSOR coordinators reported on a long period for creating a common vision to work towards as well as a common language to communicate needs among the different work groups. The Competing Values Framework allocates the functions of mentor and facilitator to the first field of interdisciplinary culture.

The mentor function involves three primary duties, the first being concern for different needs within the project team. In our case of inter- and transdisciplinary research management, the CEC guidelines prescribe, for example, gender equality (CEC, 2003), and the literature on interdisciplinary management reminds us to consider career possibilities of involved researchers (Bruce et al., 2004; Tress et al., 2005; Wiesmann et al., 2008). A young scientists support forum and a gender task force set up within SENSOR were activities that fit under this duty.

A second duty is building commitment, implying the balancing of different personal attitudes (Bruce et al., 2004) in order to equally motivate all project partners. An open attitude for discussion and agreement was considered as highly important by the coordinators. Activities to achieve this included bilateral support and consultation by the coordinators as well as a transparent structure for decisions taken through regular meetings of all module coordinators.

A third mentoring duty is maintaining morale, which corresponds to the documentation of science and society issues in the CEC guidelines (DG RTD 2003) and the establishing a climate of fairness and professional ethical attitudes in SENSOR. Clear communication of and compliance with timelines, regulations and financial issues as well as an open discussion of Intellectual Property Right issues can contribute towards fulfilling this duty.

The facilitator function involves the duties of providing means for discussion and participation, while maintaining openness. Mutual learning and shared goal definition can prepare the ground for knowledge production (Hollaender et al., 2008, p. 385) if communication and knowledge exchange serves cooperation and teambuilding. Related to this is a sense of avoiding administrative overload (Wiesmann et al., 2008, p. 438). SENSOR coordinators reported that a combination of modern communication means and arrangements for ample discussion along the management chain could help to balance democracy and transparency against information overflow and chaos. A tailored project-internal website would not replace multilateral email contact, but could help to keep communication brief and clear. The number of communication channels should be limited and take into consideration community-specific communication patterns (e.g. email versus discussion forums). Participation includes possibilities for project partners to be involved in different tasks, along with the acknowledgement and visibility of their contributions. Presentations of project partners at project meetings, reference to individual authorship of all project documents and visible documentation on the project website and project reports were measures in SENSOR to support this.

To support interdisciplinary comprehension of projects tasks, management may be responsible for translation between the involved disciplines and knowledge management. Both duties were therefore added as functions of the SENSOR team of module coordinators, who consequently served as an interdisciplinary "think tank". We see this kind of extended management as a core group seeks to ensure integration and innovation by translating interdisciplinary concepts for the particular disciplines represented (in SENSOR achieved via a glossary available on the project website), which helps to fill in knowledge gaps. This reflects the common experience that no inter- or transdisciplinary researcher is an expert in all fields (see also Klein 2008, p. 408). Establishing a communication flow between different layers of disciplinary levels could effectively make disciplinary knowledge available for discussions, filling knowledge gaps with up-to-date research. Thus, we think progress can be made to reduce the impression of "triviality" that interdisciplinary solutions sometimes bear.

3.2. Research output

The second quadrant of Fig. 4 represents integrative product development of trans- and interdisciplinary research, here understood as the research output. One intricacy of integrative research is the need for balancing integrated and – from a disciplinary viewpoint – sometimes seemingly trivial results of integrated research against the in-depth and detailed results of disciplinary research. Experience from SENSOR seems to indicate that a fruitful interdisciplinary culture depends largely on making clear decisions on when to work disciplinarily and when to integrate, since the motivation of individual researchers is clearly linked with disciplinary knowledge production, while the success of the project team depends on integrative product production. There is a need for a form of management that can effectively support equilibrium. The Competing Values Framework indicates the director and producer functions as being important toward achieving the goal of research output.

With the producer function, management is expected to guide, monitor and support research output. Contracts with funding bodies form the basis for the needed productivity in terms of quantity and quality (deliverables and milestones) as well as its accomplishment. In order to ensure the impact of results, they have to be made public to the scientific community, the target audience (e.g. in our case: policy makers) and the wider public. A precondition is also identifying and communicating potential impacts and applications of results within the project consortium. EC guidelines prescribe that management should formulate a plan for publication and dissemination (DG RTD 2003). Therefore, integration needs to be planned as well (Tress et al., 2005), which in the case of SENSOR was achieved through integrative concepts for effectively supporting impact assessment of land use policies.

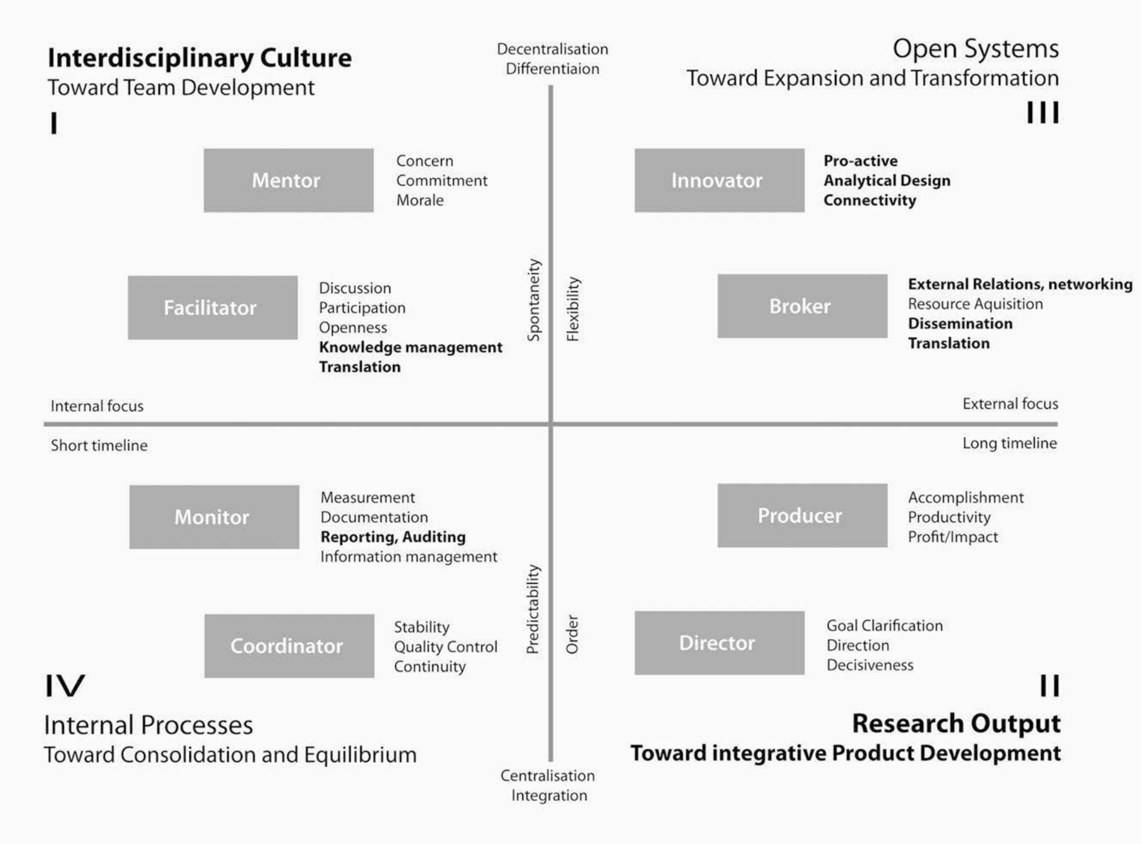

Fig. 4. Framework for interdisciplinary research management.

Adapted from Quinn (1988).

The director function was not so explicitly discussed in the respective interdisciplinary management literature, but this function must certainly differ from its role in a business organisation or enterprise. In our case study, this role was attributed to the coordinator in consultation with the steering committee and the module coordinator committee.

The director function of goal clarification seeks to ensure that a common language and shared goals are achieved (Pickett et al., 1999). To develop a common conceptual framework for integration, it is crucial to achieve coherence among the existing multiple, separate preceding disciplinary perspectives, to weave them together and at the same time advance mutual understanding (see Boix Mansilla and Gardner, 2003; Hirsch Hadorn, 2005). Although this is the basis for producing targeted and consistent results, deriving logically consistent concepts and results across disciplines is usually a time consuming process (Pickett et al., 1999). In SENSOR, it took an estimated one and a half years until common ground had been found amongst the project partners – a commonly reported characteristic for large and interdisciplinary consortia. Especially the systematic structuring and modelling of the problem field (Hirsch Hadorn, 2005) was finally successfully tackled by the coordinator through conducting many intensive discussions and numerous e-mail exchanges striving to achieve consistent and repeated goal clarification and re-focussing at all stages of the project to match the perspectives of end user and consortium.

A certain degree of decisiveness and direction is helpful for supporting the process of result production and integration, iteratively shaping the integrative concept and internally organising a joint and coherent research strategy.

Trying to balance research output on the one side and the interdisciplinary culture on the other may at times bear a potential for conflict, revealing that the two managerial functions – here the producer and director roles – can have different targets at different stages of a project's lifetime.

Integration and goal orientation is a time-consuming communication process, requiring an open atmosphere. This internal concept and consensus finding has to be interlinked with the research conducted in order to take up end user needs and expectations towards the final product. Within this context, the director role for management of making decisions towards integration and product development is one solution which has also been discussed by Adler et al. (2009). Interdisciplinary management implies a distinct and diplomatic form of temporary leadership, which needs support from project authorities (management structure: steering committee, peer group) as well as from research institution leaders. However, the director role is seen as being somewhat contradictory for the culture of the scientific community (Adler et al., 2009).

3.3. *Open systems*

The third quadrant of Fig. 4 – leading towards expansion and transformation – implies the highest degree of uncertainty, since it deals with management of the external arena, which in our case is the interface between science and policy. Engagement of scientists at the science–policy interface is in many cases experienced as being rewarding, but more often as immensely frustrating (Pannell and Roberts, 2008), given the reportedly poor uptake of research results in policy-making processes. While much research has already been dedicated to discovering the reasons for this low-adoption phenomenon (e.g. Lackey, 2007; Pielke, 2004, 2007; Saretzki, 2005), others are trying to reveal mechanisms that may support knowledge transfer towards action (e.g. van Kerkhoff and Lebel, 2006). In the light of the previous mentioned research in the field of knowledge transfer between science and policy, the Competing Values Framework proposes two functions, the innovator and the broker, that can help to manage such barriers.

The role of innovator implies insight into user needs and their translation towards adaptation within the research context to develop novel solutions. The innovation of inter- and transdisciplinary projects lies in successfully formulating an integrative concept that is coherent across disciplines, scales and regions. It also lies in the development of tools to process scientific evidence such that it can be comprehensively fed into the policy process.

Kueffer and Hirsch Hadorn (2008) use the term "boundary management" for managing a project's external relations in inter- and transdisciplinary research. The Competing Values Framework proposes the broker function, which includes the duty of securing external support for the validity of the research topic and resource acquisition to secure funding for further project and product development. Miyashita and Nakamori (2007) propose the role of an intermediary for the translation and transformation of scientific knowledge into policy-relevant knowledge. This role, however, refers to a linear model of science–policy interaction, while the SENSOR research process consisted of an iterative exchange between the funding body (DG research), the potential users of the developed tools and methods, and the researchers. Therefore, the broker function also involved the trading of information about societal challenges, research questions and knowledge produced. One of the main challenges of SENSOR was that the potential end users could neither be clear about their needs regarding organisational structure and political processes nor about the properties and features of the research products they needed, due to ongoing developments in their sector. Since the process of Impact Assessment establishment at the European Commission was ongoing, it was futile for the researchers to wait for definite requirements to be set by the end users, who were interested in seeing how the developed tools could meaningfully support policy makers at all (Tabbush et al., 2008; Thiel and König, 2008). Thus, SENSOR was involved in an iterative process of shaping the field of method and model use, which at times led to the impression among researchers of being far ahead of political developments. As one project member stated: "We are flying around in a jumbo jet, while the others are trying to get their bicycles working." Here again, the task of translation and transformation serve the function of brokerage. SENSOR adopted this role with various tasks of dissemination (targeted presentations, newsletters and brochures) to ensure a two-way information flow. To a large extent, it seemed to be the existence of the project itself that fulfilled the role of an intermediary.

3.4. Internal processes

The fourth quadrant of Fig. 4 addresses the internal organisation and administration of a project, mainly determined by the guidelines from funding institutions. Here, the challenge reported by the SENSOR coordinators was to achieve a balance between clear project management with strict deadlines, division of labour and communication procedures on the one hand, while providing room for plurality, creativity and adaptive production on the other. Due to the administrative requirements of the funding organisation, integration of all research tasks into one final product required close meeting of deadlines for all tasks. Delays of central work packages (Sieber et al., 2009; Morris et al., 2008) could endanger project outcomes, making adaptations and re-adjustments of the research process necessary. The Competing Values Framework allocates monitor and coordinator functions to the internal processes taking place. Both functions are grounded in a more universal administrative language and only to some extent require project-specific adaptation. The duties assigned can be considered time-consuming, but basic requirements.

The coordinator function involves the application of administrative rules from funding bodies: in the process creating and maintaining routines and internal stability. In the SENSOR case, EC guidelines prescribe the overall legal, contractual, ethical, financial and administrative management and maintenance of the consortium agreement (DG RTD 2003). Control of financial issues and project progress is crucial for the timely production of meaningful results. For SENSOR, quality control was ensured via the establishment of an internal review of project deliverables. Continuity can be supported by management through constant communication flows, meeting routines and reliability regarding implementation and control of jointly taken decisions.

The monitor function includes the duties of measurement (finances, work-plan fulfilment), documentation (reporting, auditing) and information management. In SENSOR, administrative rules were flanked by joint training courses, partner-specific templates and "rehearsed" reporting. This facilitated learning, established routines and limited the administrative load. A secondary effect was an increased reliability of partners vis-à-vis coordinators. Needless to say that administrative necessities must be linked to the timeline of the project; consequently, organisational skills and the capability of linking content and timeline are important qualifications for fulfilling the functions of coordination and monitoring. In fact, this arguments for project coordination being handled by one of the research institutions rather than being outsourced or taken over by EU-level management. Interestingly, even long before the end of the SENSOR project, administrative routines were accepted by all partners and treated separately from personal communications or questions of research orientation and integration. An agreement to keep payments to a partner on hold in case of non-delivery was reserved as a last-resource "stick" for the management to foster integration, but was never employed. A contingency fund proved useful for ensuring flexibility in re-shaping research processes, financing unforeseen additional work, adapting to time-consuming requirements within inclusive stakeholder analyses and the like. This lowered the tension between the low level of formal steering powers, project-internal conflicts and the need for cooperation, also regarding future cooperation with the partners in other research consortia.

The following section provides an analysis of the SENSOR management experience in terms of adapting the Competing Values Framework (see Fig. 1) in order to better fit the requirements of interdisciplinary research project management (see Fig. 4). In addition to the changes within the four quadrants, we also changed the attribution of the timeline in the adapted framework. In contrast to management within an entrepreneurial organisation, where the ultimate duty is geared towards leadership of sub-groups that will merge back into the meta-work flow after achieving a set goal, the situation is different for research groups. Research consortia form their own groups across a number of research-producing organisations and fall back into their "home structures" upon coming to the end of a project's lifetime. This can be very different, however, from the project structure for an individual researcher. Most often, the rational goal of a research project is considered to be a long-term goal, and a research consortium must be committed to maintaining the durability of processes created within the wider field of the research topic and network and valorisation of project results long after the period of collaboration. We therefore see the long timeline being attributed to external-focus issues, while the short timeline is oriented towards internal-focus ones.

To summarise the results, we feel that we have sufficiently demonstrated that application of the Competing Values Framework and its adaptation can serve as a plausible reference frame for ex post analysis of the organisational structures of interdisciplinary research projects.

4. Discussion

Policy makers ask scientists to deliver information that can help them to grasp the bigger picture by, for example, revealing key causal relationships, illustrating developments, enabling evaluation and providing orientation concerning future developments (Kropp and Wagner, 2007, p. 14). Sustainability assessment, including assessment of conflicting targets, is one field where policy makers ask for scientific expertise to balance emotional public debates and to avoid debates when making at times risky and controversial decisions through neutral scientific evidence (Bogner and Torgersen, 2005, p. 7). Science with a policy perspective should make a broad range of action options visible for decision makers, providing state of the art scientific knowledge for each option (Pielke, 2004, p. 415). An emerging means of providing such overviews on impacts of policy options are computer-based tools that have proven useful in other contexts for supporting decision-making processes on international environmental issues (Castells and Guardans, 2008; Helming et al., 2011b). Science and policy are two societal fields reflexively influencing the preconditions of action for each other: Science policy frames the conditions of knowledge production, while scientific knowledge provides grounds for legitimising political decisions. Consequently, scientists have to be aware of and deal with the spectrum of political perspectives in order to make scientific advances useful for enable political framing, such as for sustainable development. At the same time, scientists are ethically bound to their professional standards, which impose strict rules on research design, investigation and communication of results.

Efficient and relevant policy research entails consideration of policy requirements already established prior to the onset of the research project design. Based on our research and experience, the most difficult task of management appears to be creating effective links between end-user requirements, research integration and results production, although we consider this the basis for being able to systematically develop products appropriate to user needs, a properly identified institutional environment and a feasible project dissemination strategy (see König et al., 2009; König and Diehl, 2009). This brings us back to the notion of "boundary management" in inter- and transdisciplinary projects, as described by Kueffer and Hirsch Hadorn (2008). Currently, such research projects are usually designed by more or less interdisciplinary groups of scientists acting with the intention of closing knowledge gaps in their particular fields of research. However, these knowledge gaps might not be identical with those identified in the policy-making process. Moreover, policy making might require an altogether different perspective on the research issue and use of different methodological approaches. These perspectives and questions have to be considered in order to make research results suitably exploitable for policy design. To overcome this inconsistency, end users, in this case policy makers, should already be involved in identifying the research questions, framing the research design as well as in selecting required expertise (De Smedt, 2011). Also, incentive systems for research as well as evaluation criteria should address performance issues that may affect efficient science–policy interaction. Research has to be carefully designed to reflect policy maker's needs, including the selection of relevant spatial and temporal dimensions associated with the policy question at hand (Helming and Pérez-Soba, 2011). This "ideal" approach is hindered by numerous restrictions, such as different priorities, sensitive issues that may underlie the policy process, reward systems, time frames, communication styles and institutional structures and cultures (e.g. Pannell, 2008). In order to overcome such obstacles, means of facilitating transdisciplinary research that support research designers in adopting the perspectives of policy makers in the elaboration and execution of research projects are warranted. Consequently, methods for information gathering within the end-user arena (Thiel and König, 2008) should be considered in the research design process as early as possible.

Although a direct influence of research results in the funding topic "sustainable land management" on policy processes in the field of impact assessment is not yet evident (EC, 2009b), SENSOR and similar integrated projects are seen as novel approaches for the development of concrete tools, as landmarks in linking science to policy and in establishing expert communities (EC, 2009b, p. 103f). A procedural view on SENSOR's research reveals that circumstances changed the primary research question from one of impact assessment tool development to an investigation of the characteristics of such a tool, illustrating that "scientific independence" in anticipating and proposing solutions can be a crucial part of such projects. This is called the constructive science approach (Pickett et al., 1999). Also, ex-post evaluation of SENSOR's and similar project's 6th Framework Programme sub-priority area "Global Change and Ecosystem" acknowledged that impacts of the project could not be fully assessed at that time, due to the time lag between project end, publication and the time-consuming, cumulative dissemination of results following the project's completion (EC, 2009b, p. 18). What is more, we consider this result to be important for science policy in that it needs to leave some degree of target and result openness for projects. As the 6th Framework Programme of the EU has also been evaluated as not having been sufficiently linked to some of European Commission's Directorate Generals' demands for policy support (Rietschel et al., 2009, p. 59), a future goal in project management could be greater involvement of scientific administrators and potential end users in the process of reframing goal details and products, so that relevant and targeted research output can be better assured.

Our adapted Competing Values Framework coherently frames the function to be fulfilled by project coordinators, which have been explicit, but not framed in the literature on interdisciplinary management before. It enables to comprehensively set up project design and is accounted for in a more rational and systematic way. We claim that even in a small project, where only one person would be required for all coordination functions, the framework could help to sensitise the project manager to the duties he/she is expected to fulfil in the course of the project. Nonetheless, since satisfactory fulfilment of all functions would be a major challenge for a single person, we concur with Adler et al. (2009) in concluding that overlapping or task-divided teams are necessary to carry out the diverse management functions, facilitate integration and share pressures associated with the leading role. Ideally, the latter need to have, in our opinion, the same or similar capabilities and skills to follow the whole process – but can also work with a more narrow focus on certain functions in a coordination team. Outlining the different management functions in large interdisciplinary research consortia in the present article, as well as analysing the case study, has also revealed the necessity of obtaining sufficient funding and suitable personnel for such projects. While, on the one side, researchers with a good overview of project concepts and methods are crucial, it is also important to ground their work in an environment of reliable and sound administrative support.

Different functions from the four quadrants of the Competing Values Framework become more or less important at different times – most of which can be scheduled (e.g. reporting routines) – but they also need to be kept flexible with regard to developments related to actors in the target arena (end users, stakeholders). A shortcoming in terms of only one of the functions outlined above would clearly impact the work efficiency within parts of or even the entire project consortium, if not hamper the overall effectiveness of the output.

By making clear the timeline focus of the different functions, management activities can be designed to improve outputs, outcomes and impacts. Commitment to distribution of research results can be enhanced by taking up producer tasks such as pointing out the accomplishments, productivity and usefulness of research output. Thus, the impact of such research can be significantly improved.

We propose that our modified Competing Values Framework can be used to better allocate personnel resources and skills as an input to the integration of research. Making explicit the kinds of input needed in addition to financial resources and disciplinary research backgrounds, project management can seek to justify the importance of managerial support and the use of brokers or brokerage tools to bridge the gap between science and policy. Interface management is a key competence, supplementing the disciplinary knowledge of project leaders. Overcoming communication difficulties associated with the external arena, namely at the science–policy interface, has been recognised as being significant for success and, therefore, remains to be mutually resolved between scientists and policy makers. Here we see a need for development of methods and research designs that allow for effective mutual information flow between researchers, end users and stakeholders. Interdisciplinary coordination capabilities are an extra qualification which is of crucial importance for the overall project success, but not universally available, as personnel has to be developed and management function details adapted to project circumstances. Unfortunately, however, the research sector does not yet sufficiently reward management experience of scientists. Therefore, the view is held in the interdisciplinary management literature, that the most relevant factors still seem to be coordinator motivation and risk propensity in terms of project achievement and career uncertainty (Truffer, 2007). However, we consider our framework to be a suitable means for communicating required management functions and personal capabilities to science policy makers and scientific administrators thus providing them with a basis for developing such interdisciplinary skills (capacity building). Therefore, agreeing with Adler et al. (2009), we advocate alternative career paths in research-project management and improved reward structures for managerial experience for scientists in the research sector.

5. Conclusions

This paper is a contribution towards defining a plausible concept for support of interdisciplinary research management. It has been aimed at filling the gap between a missing theoretical framework, on the one hand, and increasing need for practical experience and know-how in interdisciplinary research management on the other. In order to develop the framework, we used a case study, document analysis and a literature review and documented action, seeking to provide useful insights into the field of interdisciplinary research management.

Based on our case study of the interdisciplinary SENSOR project, we have adapted the Competing Values Framework (Quinn, 1988; Quinn and Rohrbaugh, 1983) towards becoming a suitable map and sense-making device for locating functions, demands and potential conflicts in research project management. The result of this adaptation process, which we have called the Interdisciplinary Research Management Framework, seeks to provide a structured, comprehensive overview of the roles, functions, duties and tasks connected to the necessities of interdisciplinary project management. Building upon knowledge regarding interdisciplinary research and relating managerial actions to the respective funding guidelines (in our case: those of the European Commission), a key asset of the framework is that it is open to further adaptation and extension.

Application of the Interdisciplinary Research Management Framework in the organisational design of a project can help in setting up efficient work flows and functioning structures within a project consortium and management team. During a project's lifetime it is a useful tool for understanding tensions that can arise and for analysing the strengths and weaknesses of its management. Furthermore, the framework provides orientation for project managers and funding institutions in evaluating large interdisciplinary projects. With our conceptualisation of the dimensions to be balanced by the administrative (Internal Process), scientific (Research Output), interdisciplinary (Interdisciplinary Culture) and interface (Open Systems) management of the project, we wish to contribute more plausible insight and guidance for understanding and learning in this field. Finally, we consider the framework to be a suitable model for facilitating growth of the discourse regarding challenges and good practice between scientists, project coordinators and funding organisations. As experience from interdisciplinary projects increases, it may be appropriate to add more specific tasks within research seeking empirical validation and further refinement of the framework. Especially quantitative validation of the proposed framework and further qualitative analysis across coordinators and participants from other projects could help to further test and develop our ideas. Nonetheless, we should point out that the process of "re-inventing the wheel" in complex and heterogeneous interdisciplinary research projects seems to remain, to some extent, a necessary, repeated learning process for producing context-specific integrative results.

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Maintaining a Research Network in the Post-funding Phase: Activity-based Model Profiles for a Durable Integration Structure

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ABSTRACT

Research consortia funded on a 3–5 years project framework make knowledge available to government departments, community groups and clients from civil society. Thereby, the research consortium may take on a boundary spanning role towards bridging an institutional gap in newly evolving areas of public interest. In recognition of this benefit, research funding programmes increasingly require researchers to maintain this role beyond the funding phase of a project. Our objective is to identify and assess a suitable structure for durable integration at the interface of research and policy. We focus on an example of a European Commission funded Network of Excellence (NoE) known as LIAISE. We used a framework of heuristic elements of coordination in organisations with a temporary nature to discuss two possible end-points: 1) a constructive solution valued by a majority of researchers in the case study; 2) a more distinct profile relevant to a sub-set of researchers.

Keywords: science-policy interface, change management, coordination, business-model innovation, research management

1. Introduction

Research consortia funded on a 3-5 years project framework often form an environment from which researchers can offer data, products and services to groups concerned with a topic of societal relevance (Schmid et al. 2016; Bruce et al. 2004). Classified as intermediary organisations with shared common objectives and a temporary nature (Hessels, 2013), the research consortia are expected to realize the full potential of research data and tools in an application oriented environment (Klerkx et al. 2017; Schut et al. 2016; McIntosh et al. 2007; Arranz and de Arroyabe 2006). Researchers engaging in transdisciplinary cooperation have become increasingly aware of their role as a resource of knowledge that can be tapped not only by industry, but also by government departments, community groups and clients from civil society (Bonaccorsi 2010; Bammer 2005). Specific values are seen in the emergence of leading roles in the organisation and creation of new pathways for knowledge transfer at the science-policy interface. Thereby, the research consortia help to overcome fragmentation in specific research areas (Edelenbos et al. 2017; Breschi and Cusmano 2004; Turner and Müller 2003) and fulfil an important function of bridging gaps between established sector-oriented organisations as well as for newly evolving areas of public interest (Fonseca et al. 2017; Buanes & Jentoft 2009; van Lente et al. 2003).

The perceived usefulness of temporary coalitions arising from time limited research projects has led to an initiation of funding programmes aimed at achieving lasting capacities for knowledge sharing beyond a project-based partnership. In the European Union, Networks of Excellence (NoE) were introduced by the European Commission in the 6th and 7th Framework Programmes (2002–2013) to support research integration around a specific topic. Each NoE had to prepare and submit a Programme for Joint Activities that stated clearly the reason for establishing a consortium and its prospects for maintaining its functions at the conclusion of EU financial support (Luukkonen and Nedeva 2010; Bonaccorsi 2010). The resulting organisation was coined a Durable Integration Structure (DIS) by the European Commission (EC 2003; EC 2010). The expectation summoned research consortia to involve in the design of organisational structures that last beyond a project lifetime. However, where success is measured in the interplay of many variables, replication of successful transformation often fails (Breschi and Malerba 2005). The transformation from a project to an organisation with permanent objectives and a much higher degree of formalisation is therefore not regularly achieved.

Previous examinations of research consortia have focused on the formation (Kaiserfeld 2013; Breschi and Cusmano 2004), value creation (Allee 2008), performance (Arranz and de Arrobaye 2013), functions (König et al. 2013), coordination and governance (Hessels 2013; Provan and Kenis 2007) and funding strategies (Lepori 2011; Braun 2003). Co-evolution and path dependence are key elements in the development of functions, structures and relationships within the consortia. New approaches to research coordination were found particularly relevant in research activities based on a problem-oriented mix of disciplines described as mode 2 knowledge production (Hessels and van Lente 2008; Nowotny et al. 2003; Gibbons et al. 1994). The overall challenge in this respect is to retain the fundamental integrity of research institutions, and to establish an organisational architecture that allows linking of activities at the science-policy interface beyond the funding phase of the project (OECD 2013; Braun 2003). Specific challenges include the coordination of structural changes, incentives, procedures and funding which depends to a large part on an exchange of experiences, learning and capacity development (Schut et al. 2016; van der Meulen & Rip 1998).

At the example of the European Commission funded Network of Excellence LIAISE, we conducted two snapshot analyses using a case study approach (Eisenhardt 1989). The analysis was conducted in the last phase of the project during the discourse on viable ways to achieve a permanent organisation. We thereby focus on the translation of coordinative and managerial aspects relevant in project-related research management to conceptual models for value creation (Teece 2010; Hessel & van Lente 2008). Drawing on concepts of business model innovation, we analyse options for suitable organisational and institutional structures based on the activity-system of the research project (De Reuver et al. 2013; Zott et al. 2011; Zott & Amitt 2010). The overall objective was to identify suitable strategies for maintaining managerial functions of knowledge transfer at the science-policy interface in a Durable Integration Structure (DIS). In this context we addressed the following research question: What type of long-term strategic option for the maintenance of knowledge transfer functions can be derived from the specific activity system of a project consortium?

2. Theoretical background

There is a significant difference in organisational effectiveness between managing an interdisciplinary research project and a long term organisation, e.g. in terms of time planning, task distributions, team development and formalisation (Siedlok and Hibbert 2014; Lundin and Söderholm 1995). The research consortium is thereby viewed as a bounded, structured group of individuals that is linked by a temporary formal contract emerged from purposiveness and interdependent individual action.

The theory of groups put forward by McGrath et al. (2000) treats such entities as complex, adaptive, and dynamic systems. According to this theory, all groups act in the service of two generic functions: (a) to complete group projects and (b) to fulfil member needs. A group's success in pursuing these two functions affects the viability and integrity of the group as a system. Rooted in the work of Kurt Lewin, this approach draws on concepts from general systems theory (von Bertalanffy 1968) and dynamical systems theory (Abraham, Abraham and Shaw 1990).

In order to achieve the expected outcome of a DIS, project consortia follow different development paths towards a new type of organisation. This can be an exclusive scientific club such as an academy of science, a scientific association where membership is based on self-registration or a funding agency (Luukkonen et al. 2006). Other concepts highlight the outcome according to the characteristics of integrated activities conducted in the post-funding phase (De Baas and Vallés 2007), or legal and financial attributes of formal organisational structures (Sipilä and Wilén 2012) (**Table 1**).

Key steps involve the communication of a clear image of the future state of the organisation, the use of multiple and consistent leverage points to modify more than a single component, and organisational arrangements in management, resources allocation and organisational planning (Edelenbos et al. 2017; van der Meulen & Rip 1998; Nadler 1993). The inclusion of a management perspective into the design of group objectives can contribute to the unpredictable development of project organisations which are subject to contradictory demands from the different spheres of science and policy (Floricel et al. 2014; de la Mothe 2003). Each development path has significant implications in terms of integration and maintenance. König et al. (2013) point out a quasi-necessary process of "re-inventing the wheel" conducted in form of a learning process within any project that sets out to produce context-specific integrative results via the creation of organisational structures. A normative transformation pathway of a research consortium is illustrated in **Fig. 1**, covering three phases of development.

The *project phase* describes the consortium of individual researchers from different research organisations based on self-organisation and with sufficient resources to reward the individuals involved (Braun 2003). Individuals contribute with skills and expertise towards an objective that is to a certain extent distinct from the research agenda of each participating research organisation (Burke and Morley 2016). The consortium is formalised through a contract to pursue the objectives laid down in a project plan; e.g. with the European Commission in the case of an NoE (Luukkonen et al. 2006).

Table 1 Attributes relevant to the creation of DIS arising from European NoE.

Attributes	Definitions	Authors
Incentives and entry barriers related to types of organisations	The position of a network in a principal-agent relationship, where an agent accepts resources to further the interests of the principal.	Luukkonen et al. (2006)
Funding agency	- Intermediary with low degree of integration	
Research organization	- Agent with high degree of integration	
Scientific association	- Quasi-agent with low degree of integration and a wide expansion of membership	
Network of Excellence	- Intermediary or quasi-agent with low degree of integration	
Principal activities	Principal components of integrated activities according to the mission of the network.	De Baas and Vallés (2007)
Research roadmap	- Resources allocation for a common research area	
Joint infrastructure	- Resource sharing based on annual activity plan	
Educational Programme	- Joint technology transfer and training programmes, capitalizing on the potentials for education	
Commercial services	- Joint engagement in development, and common use of intellectual property rights (IPR)	
Organisational structures	Legal and practical aspects for integration based on financial structure and business profits	Sipilä and Wilén (2012)
Ltd company	- Shareholder based, for profit organization	
Economic interest group	- Member fee based, for profit organization	
Association	- Member fee based, non-profit organization	
Consortium Agreement	- Cost based, non-profit organization	
Coordination processes	The coordinating mission of an intermediary organization by distinct interventions and mechanisms.	Hessels (2013)
Bundling research plans	- Collective negotiation for research funding	
Alignment with parent organisation	- Knowledge sharing and strategic collaboration for strengthened legitimacy in industry involvement	
Alignment with other parties	- Formal or informal collaborations e.g. with industry	
Research programming	- Consultation for achievement of research relevance	
Competitive project selection	- Selection of projects based on formal set of criteria	
Bureaucratic efficiency	- Organizational standards in procedures	
Protection of IPR	- Rules for communication before exploitation	
Interaction in programmes	- Regular exchange for shared common goals	
Levels of integration	Type of knowledge integration and the durability of the context of that integration.	Siedlok and Hibbert (2014)
Sourcing	- Disciplinary research output is employed on a problem-oriented project basis	
Consolidating	- Tools or approaches become core elements within a recipient discipline	
Synergising	- Two (or more) disciplines jointly combine their approaches within a defined project	
Configuring	- The combination of knowledge allows a new hybrid disciplinary community to evolve	

The *transformation phase* describes the intermediate phase where researchers negotiate project outcomes and follow-up activities as representatives of their organisation. Thereby negotiation processes between consortium members amongst themselves as well as between consortium members and their respective home organisation become increasingly prevalent (Podolny and Page 1998). This phase is characterised by declarations of intent that can be codified in a charter or memorandum of understanding, or a business plan (Thomas et al. 2011; Bonaccorsi 2010).

The *post-funding phase* describes the final outcome of organisational transformation in form of a DIS expressed in a formal contract for cooperation between institutions, often with multiple enduring tensions between the respec-

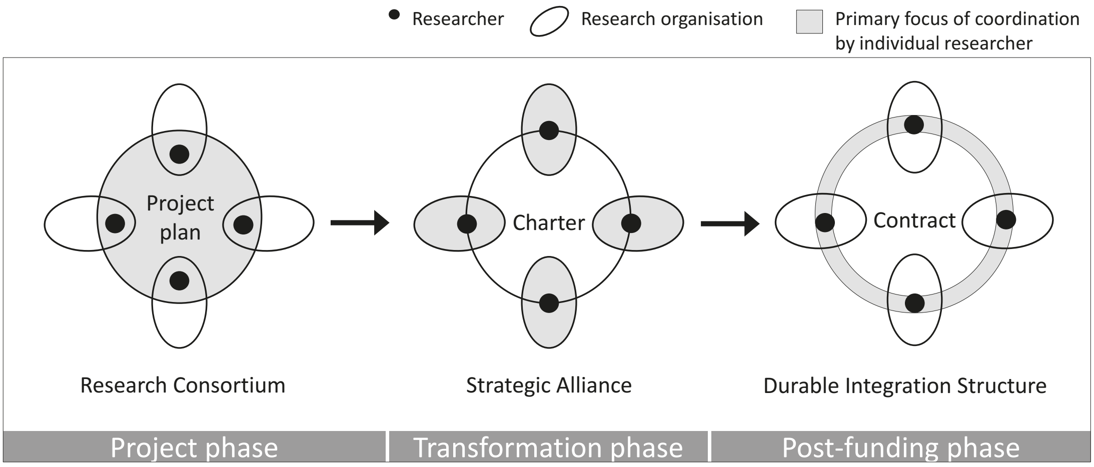

Fig. 1 Generic transformation from a research project to a DIS.

tive actors (Parker and Crona 2012). Long term strategies, knowledge and technology transfer in addition to publication and dissemination activities need to be harmonised with the strategies of each respective research organisation (Hessels 2013). Alternatively the project disintegrates resulting in a disbandment of the project consortium.

The rise of intermediary organisations with a coordinating mission still requires an enhanced understanding of the emergence and persistence of DIS born out of research projects (Luukkonen and Nedeva 2010). Drawing on Lepori's (2011) approach for coordination in science, Hessels (2013) proposes a heuristic framework for the analysis of intentional coordination processes identified within a NoE, where coordination is defined as "the establishment or strengthening of a relationship among the activities in a system, with the aim to enhance their common effectiveness". The heuristic framework considers seven elemental aspects to describe research coordination processes: a coordinating actor, the system addressed, activities conducted and interventions taken, as well as types of relationships, mechanisms and performance. It was specifically developed to describe coordinative aspects in the development of a research consortium of an NoE. Due to its functional approach, the framework allows for a systems-oriented analysis of coordination processes in regard to maintaining the coordination functions of a research consortium. We apply this framework as a lens for analysing one research project in the phase of transformation (phase 2 in **Fig. 1**). Considering that a DIS will imply a financial revenue model, we added "sources of revenue" as an additional aspect (**Table 2**).

Table 2 Questions identified to illuminate processes during the transformation phase, structured by a framework of heuristic aspects of research coordination (Hessel 2013).

Aspects of coordination	Questions adapted to the LIAISE NoE
1. **Coordinating actor**	What is the self-conception of the researchers in regard to their own role and position towards the group? (e.g. as contributors at an individual or group level)
2. **System addressed**	Which system area should preferably be addressed? (e.g. target groups in a specific field)
3. **Activities subject to coordination**	What types of activities should preferably be supported in the long term? (e.g. of those conducted during the project phase)
4. **Interventions taken**	What types of interventions are considered effective and successful in regard to the objectives of the research consortium?
5. **Types of relationships**	What types of relationship are preferred in the research consortium? (e.g. collaborative, complementary, synergistic or synchronised)
6. **Mechanism for effectiveness**	What effects are expected within the group due to the mechanisms applied?
7. **Performance aimed at**	What impact is attributed to the performance of the consortium? (e.g. in terms of monetary or non-monetary values)

3. Methods

Our case study example was known as LIAISE, an NoE funded by the European Commission to support impact assessment for policy appraisals at European level. A two-tiered snapshot analysis was set up, informed by participatory observation and workshops on the one hand, and a standardised questionnaire survey completed by coordinating researchers from each participating research organisation involved in the NoE.

3.1 Case study: LIAISE NoE

The LIAISE NoE was funded to support research for the integration of social, environmental and economic aspects in ex ante assessments of policies for sustainable development. Policy appraisal is one field of applied science that requires a high amount of knowledge and data integration (Turnpenny et al. 2009). Research and policy practice were found to have partly developed in parallel or even been drifting apart due to a technical-rational approach on the policy side and a need for deliberate and reflexive structured processes for knowledge brokerage on the side of research (Adelle et al. 2012; Owens et al. 2004). The LIAISE research agenda arose from the conclusion that the full potential of European scientific research output in the field of impact assessments was not being realised by the European Commission and the European member states (Adelle and Weiland 2012; de Smedt 2010).

LIAISE was to provide integrated knowledge and to become a hub for methods and tools facilitating integrated assessments for sustainable development. The aims entailed the provision of a one-stop-shop for activities that link academia to the larger social system. Next to a methodological advancement in participatory methods and knowledge exchange, the characteristics of integration and implementation activities were to comprise institutional learning, systematic reflection, building of overarching associations and agenda-setting.

The NoE started in 2009 with 16 research institutes and 80 researchers from 9 European countries. It was funded by the European Commission FP7 programme to achieve three strategic goals: 1) to bring together research organisations in a virtual centre of excellence, 2) to develop a platform for structured dialogue between researchers and policy actors involved in impact assessment, and 3) to maintain this achievement beyond the project period.

3.2 Participatory observation and workshops

The analysis of the transformation had the aim of identifying activities, benefits and services that are valued and likely to be supported by the researchers in the post-funding phase. Participatory observation was informed by an approach of researching the researchers described by Coghlan and Brannick (2005). In this approach, members of the system which is being studied participate actively in a cyclical process of knowledge integration. This serves to solve real organizational problems while simultaneously bringing about the organisational change.

The guided process in LIAISE was effectively started midway through the project to create an open discussion with all involved researchers on the potential focus of the DIS at an early stage of the development process. The process was guided by a team of researchers responsible for governance and post-project durability, in close cooperation with the project management board. The decision making entity was the General Assembly with one representative of each organisation. Guidance and monitoring were framed to address relevant procedural issues in the transformation phase, and to add to the discussion with scientifically based concepts of organisational planning. A meeting of the General Assembly was held in New Lanark, Scotland, 18–20 June 2012 (Jones et al. 2012). The process was further structured by 3 subsequent workshops conducted with coordinators in the NoE. The results were communicated at the final general assembly meeting in the Netherlands in January 2014 (LIAISE Charter 2014; Dick et al. 2014; Jansen and Janssen 2014).

3.3 Standardised questionnaire survey

A standardised questionnaire survey was conducted three months after the end of the project in July and August 2014. It was used for a snapshot of researcher preferences during discourse at a time, where the consortium is either preparing for disbandment or for the finalisation of a DIS.

The questionnaire addressed the members of the General Assembly from the 16 research organisations that formed the NoE (16 interviews). These were the researchers responsible for negotiating the objectives for a common strategy due to their simultaneous function as coordinators of group activities and as formal representatives of their respective research organisation. Each interview partner was requested to answer the questions in their function as experts within the NoE as well as representatives of their own research organisation.

The survey had the aim to identify preferred aspects of research coordination and to assess the interest of the researchers to retain the identified activities and services beyond the funding phase of the project. Possible pathways and open questions were identified and structured by adapting Hessel's (2013) framework of heuristic aspects of research coordination to the case study.

Choice categories were formulated for each of the eight coordination aspects to retrieve a quantified analysis of the strength of interest in each aspect. The choice categories were formulated in close consideration of open questions and strategic options identified during process analysis. In order to avoid the risk of decreasing reliability within the relatively small set of interview partners, we kept the range of choice categories below seven, thereby following the standard advice within psychophysical studies (Cox 1980, Miller 1956). Open questions in each category did not lead to the creation of new choice categories during analysis. The complete questionnaire had 98 questions spread across the eight aspects of coordination. The questionnaire is available in an Annex to this paper.

The questionnaire design employed a 5 point Likert scale for dichotomous response options “agree” (+1, +2), “don’t know” or “neutral” (0) and “disagree” (-1, -2). The bipolar scaling method measures either positive or negative response to a statement. The range captures the strength of the response to a given statement or question. We applied a short scale of point meanings in order to keep ratings reliable and valid within the small number of *N* (Krosnick and Presser 2010, Schaeffer and Presser 2003).

The response data to the questionnaire survey was analysed using basic statistics. The aim was to identify aspects of coordination that would indicate a suitable structure for maintaining the NoE beyond the funding phase of the project. 15 interviews were analysed (N=15).

In a first step, the interest of the respondents in the aspects of coordination addressed in the questionnaire was calculated. The strength of answers was reflected by the sum of positive and negative responses (∑ Likert) per question. The sum of positive and negative responses was plotted in absolute numbers (abs). With a Likert range from -2 to +2 and N=15, the lowest potential interest that could be attained was 0 and the highest was 30. The result was reported as percentage of interest *i* in relation to the potential Likert points which could be attained in each question *(a)*.

(equation a) interest $i = \text{abs}\,(\sum \text{Likert} \times 100)/(\text{N} \times 2)$

While the distance to 0 marks the interest within the group of respondents in regard to the coordination aspect, it does not show whether the aspect of coordination is disputed. Therefore, the ambiguity of the respondents was analysed in a second step. Respondents with positive response (+2 and +1) were added, and reported in percentage of agreement (*agree*) in relation to the total number of respondents (n) per question. Likewise, respondents with negative response (-2 and -1) were reported in percentage of disagreement (*disagree*), with *neutral* (0) being the remaining difference. A balanced percentage between *agree* and *disagree* as well as a high percentage of *neutral* indicated a high degree of ambiguity or potentially conflictive polarity within the group of respondents towards the aspect of coordination addressed in the question (*Q*).

In a third step, we compared four strategic profiles for a DIS that were identified by the LIAISE consortium during the transformation described in the process analysis. The strategic options were associated with a set of aggregated questions from the survey questionnaire according to operational linkage. Then the strategic options were compared by mean interest *i*, mean *agree* and mean *disagree*.

In a last step, we calculated a value factor *v* for each strategic profile. Value *v* was calculated by the sum of positive response to all operational questions associated with a strategic profile. The result was reported in percentage of value in relation to the total sum of positive response (b).

(*equation b*) value $v_{\text{profile}} = (\text{positive response}_{\text{profile}}/\text{positive response}_{\text{total}}) \times 100$

Additional descriptive statistics that characterise the group of respondents were reported in the text (e.g. response to questions concerned with the coordinating actor). Where reasonable, we grouped the response into appropriate categories. A complete questionnaire with response data is provided in an Annex to this paper.

4. Results

4.1 Deliberative process of transformation

Negotiation processes between research organisations in the transformation phase of a research consortium bear a risk of evolving into lengthy discussions on “*concrete proposals that have been prepared in close collaboration with directors as inputs for a negotiation process resulting in ‘winners’ and ‘losers’*” (Dick et al. 2014). The iterative process in the case of NoE LIAISE resulted in an action plan with a timeline, duties and deliverables across several decision making levels. The schematic timeline is illustrated in **Fig. 2**, sum-

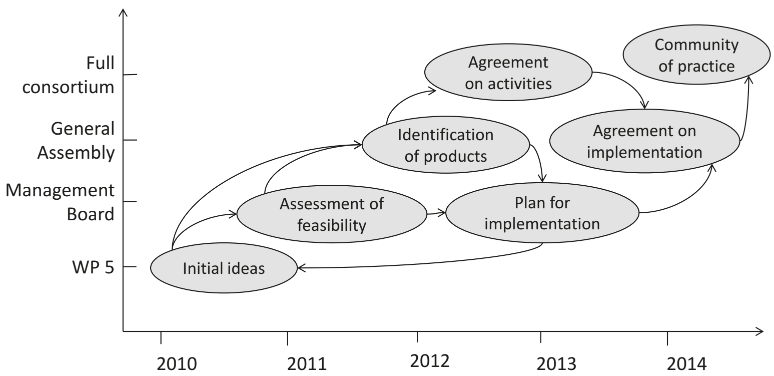

Fig. 2 Schematic timeline and actors involved in the creation of a DIS. Arrows indicate the reflexion and feedback between the decision levels.

marised from Dick et al. (2014). The deliverables to achieve a DIS for the NoE in the post-funding phase were detailed in form of activities, objectives and outcomes.

Activities conducted within the research consortium were categorised at a General Assembly workshop in June 2012. The activities were categorised by their orientation of performance ("conduct integrated impact assessments" or "do research in the field of impact assessment") and potential effects ("develop capacities in research" or "develop capacities in policy"). The main questions summarized in the workshops were:

- what activities effectively *apply integrated research* results achieved in the NoE?
- what activities further *consolidate integrated research* in the long-term?
- what activities serve the *requirements of research* in the community?
- what activities serve the *requirements of policy* in the field of impact assessment?

Four activity profiles emerged from categorizing activities within the research consortium. The profiles supported activities in training and education (TE), consultancy (CO), scientific exchange (SE) and programme planning (PP) (**Fig. 3**). The LIAISE consortium considered these profiles as model profiles for further development of organizational structures for durable integration. The objective of the General Assembly was to retain essentially all four model profiles in a DIS (Jones et al. 2012).

	Research requirement profile	Policy requirement profile
Application of integrated research	Training and education	Consultancy
Consolidation of integrated research	Scientific exchange	Programme planning

Fig. 3 Activity based model profiles identified by the LIAISE consortium for a DIS of the LIAISE Network of Excellence.

Tasks and mechanisms were identified with the aim to address multiple target groups in the field of impact assessments, namely researchers, policy units, policy experts and consultants, private sector organisations and funding agencies. The provision of meta-data, procedural principles, quality guidelines and a shared research agenda were to ensure functions of knowledge exchange, innovation and testing of methods and tools, as well as mutual learning.

The final outcome was a web-based knowledge hub that had been created to operate within a Community of Practice. A strategy encouraging self-uploading of methods, models and knowledge negated the need for complex negotiations between coordinators in regard to intellectual property rights, accessibility or governance issues. A charter for cooperation was formally agreed on by the end of the NoE in April 2014 by the General Assembly of the LIAISE research consortium (LIAISE Charter 2014; Jansen and Janssen 2014). The charter centred on the conclusion that a DIS should be "activity-based" rather than "product-based". The valuable assets were perceived in the requisite variety of skills, methods and approaches for communication and interaction within the wider sphere of science and policy oriented experts. This posture was underscored by feedback from a policy-advisory board who stated that the provision of individual products would not be a unique selling proposition for the newly emerging organisation.

Two challenges arose in the formation of the DIS. Firstly, the reflexive interaction maintained a certain amount of trial and error in goal achievement on the side of the coordinating researchers. While the process left scope for participatory involvement, the diversity of levels of experience within the consortium when building a DIS led to double looped communications before decision making. Secondly, the tasks and mechanisms that were identified to be maintained in the post-funding phase ran across all four model profiles. Due to the tacit and service-oriented nature of the activities, their value as products could not be easily quantified. Furthermore, they could not be clearly allocated to one of the four activity profiles. While the four model profiles were elegant, they proved impractical for building a consistent strategic organisational structure centred on one model profile only, mainly due to differing motivations and strategies of researchers in the consortium. In order to shed more light on the interests of the leading actors in the consortium towards the coordination of a DIS, the questionnaire survey was applied for a more detailed analysis.

4.2 Response to aspects of coordination addressed in the questionnaire survey

According to the response of the 15 coordinators in LIAISE, the consortium coordinated multidisciplinary scientific cooperation for impact assessment (Q 1.1: 87 % agree) and research for a better integration of knowledge for impact assessment (Q 1.2: 93 % agree). The partners most contributed to environmental (Q 1.4: 73 % agree) and policy (Q 1.6: 86 % agree) aspects of impact assessment as well as to the integration of aspects (Q 1.7: 80 % agree). **Table 3** shows the characteristics of the respondents, such as their institutional background and seniority, their planned amount of working hours dedicated to the group activities in LIAISE and whether support was due to the motivation of the individual researcher or the represented organisation. In total, the consortium expected to invest 70,5 hours per month over two years into the post-funding phase.

Table 3 Descriptive statistics of the respondents in the LIAISE consortium.

Q	Variable	Response	n=15	%
(0.0)	Type of research organisation	University	6	40
		Research centre	9	60
(9.0)	Personal experience in impact assessment	0-9 years	3	20
		10-19 years	5	33
		20-29 years	7	47
(8.5)	Authority to allocate funds	Yes	3	20
		No	8	53
		Don't know	4	27
(6.15)	Workload expected as input to LIAISE community in the next 2 years	0 hours	3	20
		1-5 hours	8	53
		6-10 hours	3	20
		> 10 hours	1	7
(5.14)	Individual motivation to strengthen relationships in LIAISE is bigger than the motivation of the research organisation	Yes	9	60
		No	2	14
		Don't know	4	26

Q: Question code in the survey; **n:** number of respondents.

Interest to pursue a DIS

The questions with the highest level of interest by the respondents were determined by ranking all 98 Likert-based questions according to their level of interest *i* (**Fig. 4**). Questions with an interest level below 47 % ranked in linear order (r=0,99), while questions with an interest above 47 % ranked in logarithmic order (r=0,97). The logarithmic order indicated those questions and statements that met an enhanced interest in the group as a whole, and that were marked by a high strength and un-ambiguousness in response to the survey.

Table 4 gives an overview over aspects of coordination that met an enhanced interest in the group of respondents. The percentage of respondents who agree with the statements reflected a preference for traditional frame conditions of doing research over more targeted, user-oriented research coordination. This was represented for example by a strong preference for addressing research communities by providing publications and receiving public funding. The main target group to be addressed by the consortium was perceived within the research sector and, to a slightly lesser extent, within policy units that engage in the process of an impact assessment.

The research consortium was perceived by the respondents as a group of individual researchers (Q 5.1: 70 % agree), rather than an institutional alliance between research organisations (Q 5.3: 60 % agree). Relational benefits were therefore attributed to the level of the individual researcher. The benefits were perceived foremost in collaboration within the group (Q 5.6: 87 % agree) and in complementation of activities (Q 5.7: 73 % agree). They were less perceived in competitive advantage (Q 5.9: 47 % agree) or effectiveness due to synchronisation of activities (Q 5.8: 33 % agree).

The questions of enhanced interest did not indicate specific support for any one of the four activity-based model profiles illustrated in **Fig. 3**, namely training and education (TE), consultancy (CO), scientific exchange (SE) and programme planning (PP). Therefore, strategically indicative questions and responses with an interest level below 47 % were classified according to their ability to inform on the respondents views related to the four strategic options identified by the LIAISE consortium during the transformation phase. The allocation of questions and statement

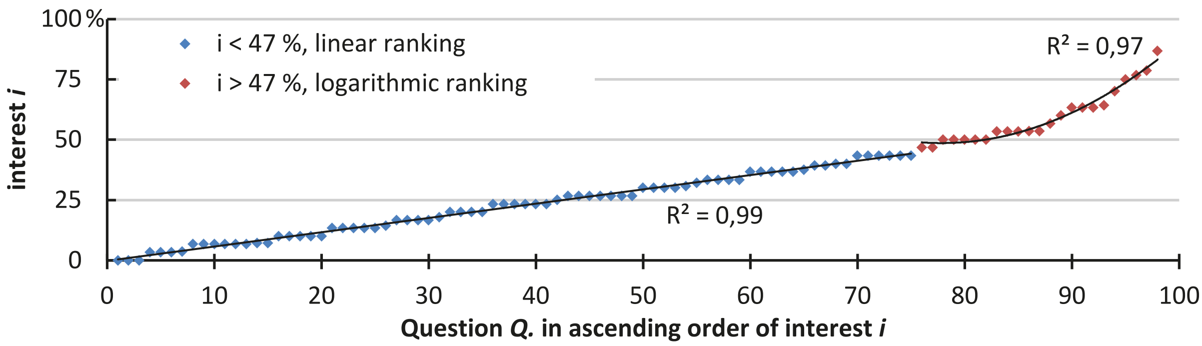

Fig. 4 Level of interest in aspects of coordination in ranked order to identify enhanced interest in the group of respondents.

Table 4 Questions of enhanced interest identified for a DIS based on aspects of coordination.

Aspects of coordination	Q	*Variable*	*n*	*i*	*agree*	*disagree*
2 **System addressed**						
Improve impact assessment activities	(2.1)	within the research sector	14	75,0	86	0
Strengthen the exchange with	(2.9)	scientific communities, research scientists and students	15	50,0	80	0
	(2.10)	policy units involved in the process of a Commission proposal	15	63,3	93	0
3 **Activities subject to coordination**						
Conduct activities such as	(3.6)	research on the design of appraisal systems (improving methods, tools, processes)	15	50,0	80	20
Maintain the following functions or services	(3.10)	knowledge and information hub	15	63,3	93	7
	(3.11)	networking and discussion forum	15	86,7	100	0
4 **Interventions taken**						
Create value	(4.1)	within the research sector	15	70,0	93	7
	(4.2)	within the policy units	15	53,3	87	13
Enhance the ability of my organisation to provide	(4.4)	tools, methods and research results for the toolbox	15	50,0	80	13
5 **Types of relationships**						
The LIAISE community	(5.1)	is a network of individual researchers	15	50,0	73	13
6 **Mechanisms for effectiveness**						
My organisation will	(6.6)	profit from the dialogue within the network	15	53,3	87	7
My organisation most contributes by providing	(6.10)	expertise via publications	15	60,0	80	0
8 **Sources of revenue**						
The LIAISE community can be best maintained by	(8.7)	public sector funding	15	56,7	93	0
Ø interest *i*				**60,1**		
Ø *agree*					**86,5**	
Ø *disagree*						**6,15**

Q: Question code in the survey; **n:** number of respondents; **i:** calculated indicator of interest; **agree:** percentage of n with positive response (+1, +2); **disagree:** percentage of n with negative response (-1, -2).

to the strategic options based on operational linkage, and their comparison by mean interest *i*, mean *agree* and mean *disagree* is shown in **Table 5**.

The distribution of interest and agreement attributed to the different aspects of coordination reflected the ambiguity within the consortium in regard to the strategic options described by the model profiles, and indicated an ambivalent attitude towards organisational change. It is notable for example that the LIAISE consortium was perceived to be aimed at an improvement of impact assessment activities for stakeholders within (Q 2.1: 86 % agree) as well as outside the research sector (Q 2.2: 71 % agree). However, aspects of research coordination clearly supporting activities outside the research sector found little agreement. One example was response to Q 7.1: "*The LIAISE community generates additional value for my organisation through commercialization of research output*" (60 % disagree). Other aspects of research coordination were either ambiguous or balanced, and thus potentially conflictive in building a strategy. For example responses to Q 2: "*To improve European Commission impact assessment my organisation emphasises the need to strengthen the exchange with consultants*" (Q 2.11: 60 % neutral) or "*with the private sector and interest groups*" (Q 2.12: 33 % agree and 33 % disagree).

Furthermore, diversifications in revenue sources for economic sustainability of the DIS found less agreement within the research consortium. The respondents preferred a DIS in the form of a loose consortium that attracts funding to each partner organisation (Q 8.1: 67 % agree) or individual contributions of the partner organisations (Q 8.2: 60 % agree). Private sector funding was narrowly rejected (Q 8.6: 64 % disagree), as was the instalment of a new entity with own funding strategies (Q 8.3: 53 % disagree).

Table 5 Aspects of coordination associated with the strategic profiles for a DIS.

Aspects of research coordination	*Q*	Variable	*n*	*i*	*agree*	*disagree*	TE	CO	SE	PP
2 System addressed: target research area of the LIAISE community										
Improve impact assessment activities	(2.2)	outside the research sector	14	39,3	71	7		x		x
Strengthen the exchange with	(2.8)	consultants (researchers and private sector)	15	6,7	13	27	x	x		x
	(2.11)	private sector and interest groups	15	3,3	33	33		x		x
3 Activities subject to coordination: activities coordinated by the LIAISE community										
Maintain the following functions or	(3.12)	innovation and testing	15	26,7	60	20		x		
services	(3.13)	tool identification and quality monitoring	15	26,7	67	20			x	x
	(3.14)	shared learning and training courses	15	30,0	73	20	x			
4 Interventions taken: activities identified to improve impact assessment at European level										
Create value	(4.3)	within the private sector	15	10,0	20	33	x	x		
5 Types of relationships: activities to strengthen types of relationships within the LIAISE community										
Relationships benefit my organisation	(5.2)	the intensity of relationships between individual researchers	15	43,3	80	13	x		X	
by strengthening	(5.4)	the intensity of institutional relationships	15	20,0	53	27	x			x
6 Mechanisms for effectiveness: commitments by the LIAISE community to improve impact assessment										
My organisation most contributes by	(6.9)	direct advice	15	30,0	67	13	x	x		
providing	(6.11)	monetary or in-kind contribution	14	7,1	36	43			x	x
	(6.12)	communication and social exchange	14	32,1	71	14			x	x
	(6.13)	technical support for researchers	15	6,7	33	20	x	x		
7 Performance aimed at: impact attributed to the performance of the LIAISE community										
The LIAISE community generates	(7.1)	through commercialization of research output	15	36,7	13	60	x	x		
additional value for my organisation	(7.2)	through communication of research output	15	43,3	67	0			x	x
The LIAISE community is expected to	(7.7)	quality of research for impact assessment	15	10,0	40	20			x	
upgrade and improve the	(7.8)	value and fit of research results	15	23,3	60	20	x			
	(7.9)	knowledge transfer across disciplines and science-policy boundaries	15	33,3	67	7		x		
	(7.10)	environment for sustainable development and impact assessment	15	23,3	60	20				x
8 Sources of revenue: maintenance of the LIAISE community										
The LIAISE community can be best	(8.6)	private sector funding	14	39,3	7	64	x	x		
maintained by	(8.8)	contracts with researchers	14	3,6	50	36	x	x		
	(8.9)	contracts with research organisations	15	26,7	60	20			x	x
	(8.10)	project funds delegated to individual researchers	15	23,3	60	13	x	x		
	(8.11)	project funds delegated to project networks	15	36,7	73	13			x	
	(8.12)	project funds delegated to research alliances	15	33,3	60	13				x
Ø interest *i*							**22,7**	**21,6**	**28,2**	**23,8**
Ø *agree*							**44,1**	**41,2**	**58,4**	**53,73**
Ø *disagree*							**28,8**	**27,8**	**17,9**	**20,36**

Q.: Question code in the survey; **n**: number of respondents; ***i***: indicator of interest in percent; ***agree***: percentage of n with positive response (+1, +2); ***disagree***: percentage of n with negative response (-1, -2); **TE**: Model profile for Teaching and Education; **CO**: Model profile for Consultancy; **SE**: Model profile for Scientific Exchange; **PP**: Model profile for Programme Planning.

Table 6 Comparison between strategic options for a Durable Integration Structure.

Comparative indicators	EI	EI+TE	EI+CO	EI+SE	EI+PP
Ø interest *i*	60,1	42,2	41,6	48,5	43,5
Ø *agree*	86,5	66,2	64,8	77,1	71,5
Ø *disagree*	6,2	17,0	16,5	10,6	12,7
Positive response in absolute numbers	169	+79	+75	+73	+87
value *v* (%)	Ø 68,3	+8,0	+7,7	+7,5	+8,5

EI: Set of questions with enhanced interest; **TE**: Model profile for Teaching and Education; **CO**: Model profile for Consultancy; **SE**: Model profile for Scientific Exchange; **PP**: Model profile for Programme Planning

4.3 Comparison between strategic options centred on the activity-based model profiles

From a practical perspective, an implementation of a DIS developed from one of the model profiles would build upon those aspects of coordination that met an enhanced interest in the group. Therefore we compared the set of questions which met an enhanced interest (EI) with a combination of this set with each of the activity-based model profiles. **Table 6** shows that the difference in interest *i* between the model profiles was not decisive. The strategic options in support of activities for scientific exchange (EI+SE) and programme planning (EI+PP) got slightly higher levels of agreement. Options in support of more service-oriented or commercial activities such as in training and education (EI+TE) and consultancy (EI+CO) were met with less interest and lower agreement.

In a last step, we compared the value *v* of the strategic options by calculating the positive response to the aspects of coordination addressed in each set of questions. This allowed for the weighting of strategic options, where the total positive response to all sets of questions reflects the total potential value that can be achieved. The value for each strategic option was calculated by the sum of positive responses to all operational questions associated with the respective option. The result indicated the percentage of value *v* of each strategic option in relation to the total value expected from investing into a DIS.

The calculation showed an average share of value *v* of EI with v_{EI}=68,3 % across all options. An additional implementation of any one of the model profiles improved the value by approximately 8 %. While the indicators for interest *i*, *agree* and *disagree* were calculated based on the number of respondents and the strength of response, value *v* considered the frequency and distribution of positive response per model profile. The ranking with this indicator shifted the most favourable profile model towards programme planning (PP) and training and education (TE).

5. Discussion

The categorisation of activities and potential services in the transformation phase of the LIAISE NoE indicates that coordinative and managerial functions of an intermediary organisation can be maintained by an activity-based model profiles centred for example on training and education (TE), scientific exchange (SE), consultancy (CO) and programme planning (PP). Each model profile in itself serves to integrate heterogeneous research-based activities perceived as supportive to knowledge transfer at the science-policy interface.

Similar profiles are reported by De Baas and Vallés (2007) upon review of 14 NoE funded in the 7th European Framework in the materials domain. These comprised a research roadmap, a joint infrastructure, educational services and commercial services. Consortia at the science-policy interface, however, differ from commercial companies as they act on a demand articulated by the policy sector that is not so much a demand for new products and services, but for the fulfilment of a certain function or role (Bonaccorsi et al. 2008, Bammer 2005). Accordingly, the DIS is not required to offer very specific products but rather generic and adaptable methods and tools as well as the process knowledge linked to their development in a form that is available to a variety of potential clients. The majority of intangible transactions are never converted into (monetary) units of measure (Allee 2008). The maintenance of these functions leads to an organisational resilience in the policy system and to stability in the production of policy relevant research results. In the field of impact assessment this is represented for example by robustness to jurisdictional requirements relevant in policy appraisals (De Smedt 2010).

The results from this case study point towards two possible endpoints for the transformation of the NoE to a DIS: 1. a less profiled and less formalised constructive basic model based on elements of research coordination which are valued by a relevant majority of researchers (Community of Practice Approach); 2. a more formalised organisation based on a more distinctly profiled activity-based model that is relevant to a sub-set of researchers involved in the research consortium (Activity-based Model Profile). The results of this study indicate that the former would be oriented towards a continuation of a project-based research network, while the latter could develop towards a profiled business model.

5.1 Community of Practice Approach

The LIAISE research consortium perceives an institutional relevance in the combination of aspects from all four profiles that is high enough to motivate further engagement in group activities beyond the funding phase. The community of practice approach is one possible translation of valued aspects of coordination into a DIS centred on the coordinative aspects that gain the highest interest in the research consortium. A community of practice is a group of people bound together by shared expertise and passion for a joint enterprise (Wenger & Snyder 2000). Compared to other possible forms of organisations, the community of practice is a less formalised, flexible form of organisation. Nevertheless, it has the potential to effectively achieve a wide range of services based on a shared perception of value that is found in interaction and joint achievement of goals (Wenger et al. 2002), thereby relating to concepts of innovation platforms (Schut et al. 2016) and boundary organisations that play an intermediary role at the science-policy interface (Cash et al. 2003). The aspects of coordination with highest response of interest (see Table 4) are in this case decisive for the architecture of an organisational model.

5.2 Activity-based Model Profile

A more profiled organisation developed from one of the identified activity-based model profiles involves coordinative aspects that are more removed from the baseline of managerial functions pursued in the project-based research consortium. It requires additional strategic adjustment and formalisation. This however entails a certain dependence on individual cost-benefit calculations. In LIAISE, a low commitment is shown by the researchers to pursue activities that do not fit the individual background and motivation. The interest to pursue one of the four activity based model profiles over the other is not significant, as long as the main benefits from being engaged in a research consortium can be retained.

In terms of value creation centred around one specific model profile, the DIS must involve a positive-sum game (De Bresson and Amesse 1991), in which people engage in both tangible and intangible exchanges to achieve economic or social good. Creating value from tacit knowledge is one of the most challenging questions in the knowledge economy (Allee 2008; Carayannis and Juneau 2003; de la Mothe 2003; Gibbons 2000). The Hessel (2013) framework can be used by research coordinators to formulate choice categories, and thus support deliberation and consolidation of interests in aspects relevant to organisation and coordination. Applying a generalised version of the questionnaire to a larger number of case studies could reveal further structural or cultural patterns, while a snapshot analysis as presented in this study provides insight into the challenges of organisational transformation with regard to context and content.

6. Conclusion

The implementation of a full-fledged business model centred on one of the activity-based model profiles remains a question of market assessment, planning and business model design. However, an explicit illustration of interest and ranking of issues can support the identification of a viable strategy to forming a DIS. Particularly the comparison of elements based on positive and negative response can support the design of a DIS by attesting and verifying potentially conflictive strategies in the transformation phase of a research consortium. The approach may thus be applied for transformative learning, for example in reducing some trial and error phases in strategic planning and design. By illustrating the process in one example, we show the weighing up of options on the basis of coordination aspects. A comparison of possible strategic options showed that the interest in pursuing coordinative aspects closer to the initial temporary project framework was more decisive than the pursuit of other more profiles strategic options, such as training and education, consultancy, scientific exchange or research programming that stood at choice.

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Appendix A: Questionnaire

Appendix B: Data Sheet

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Questionnaire on management and coordination of research partnerships in the post-funding phase of European projects

A survey conducted by Katharina Diehl and Götz Uckert (ZALF) in the frame of reviewing concepts on durable relationships for impact assessment in Europe

You were selected for this survey in your capacity as a member of the General Assembly and the direct contact for the LIAISE community within your research organization (www.liaise-kit.eu).

We address you for your expertise as an interface between the coordination of the Network of Excellence (NoE), now the LIAISE community, and the network partner organisations. We herewith kindly request you to answer the following questions in person as an expert with the strategic background within LIAISE as well as your own research organisation.

Our aim is to do research on durable relationships for research networks. We want to get a better understanding about strengths and interests of the individual partner organisations in regard to maintaining network structures particularly in the post-funding phase. The LIAISE NoE is an excellent case study for these means, as it addresses a complex interdisciplinary research area of relevance to a defined target group (impact assessment at European level).

We have prepared 8 questions, each with a selection of possible answers to choose from. Estimated time is ca. 20 min.

The survey will assess various dimensions of network relationships. As a result we aim to display and articulate the different dimensions of added value in maintaining research networks. As such, questions will also seek to identify the ability of a post funding entity to contribute to long term interests of the individual organisations.

Information about the organisations compiled in the production of this survey will be treated confidential, and will be used for analytical and statistical purposes only. Aggregation of data for reasons of publication will protect anonymity. Aggregated results will inform the LIAISE community on aspects of management and coordination in the post-funding phase.

Questions:

Please tick the response that best reflects your opinion.
The rating scale for each statement is to read as agreement:

Scale	**-2**	**-1**	**0**	**1**	**2**
Agreement	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree
			Undecided / Neutral		

In case of feeling uncomfortable with listed categories we kindly request you to give your remarks and comments in open questions or as statement in the last section.

		-2	-1	0	1	2
	1. Self-conception of the LIAISE community					
1.1	The Network of Excellence of LIAISE coordinated multidisciplinary scientific cooperation for impact assessment					
1.2	The Network of Excellence of LIAISE coordinated research for the better integration of knowledge for impact assessment					
	The LIAISE charter states several aspects of LIAISE output. My organisation has most contributed to					
1.3	… economic aspects of policy impact assessment					
1.4	… environmental aspects of policy impact assessment					
1.5	… social aspects of policy impact assessment					
1.6	… policy aspects of policy impact assessment					
1.7	… the integration of different aspects of policy impact assessment					
1.8	… other (please specify)					
	…					
	In future, my organisation expects to be represented by the LIAISE community for ensuring an efficient					
1.9	… integration of economic aspects of impact assessment					
1.10	… integration of environmental aspects of impact assessment					
1.11	… integration of social aspects of impact assessment					
1.12	… integration of policy aspects of impact assessment					
1.13	… integration and transfer of knowledge for impact assessment					
1.14	… other (please specify)					
	…					

		-2	-1	0	1	2
	2. Target research area of the LIAISE community					
	According to your own perception, the LIAISE community as it is described on its website aims to improve impact assessment activities on a European level for stakeholders					
2.1	… within the research sector					
2.2	… outside the research sector					
	The LIAISE community enhances the ability of my organisation to address					
2.3	… consultants (researchers & private sector)					
2.4	… scientific communities and research scientists and students					
2.5	… policy units involved in the process of a Commission proposal					
2.6	… private sector and interest groups					
2.7	… other (please specify)					
	…					
	To improve European Commission impact my organisation emphasises the need to strengthen the exchange with					
2.8	… consultants (researchers & private sector)					
2.9	… scientific communities and research scientists and students					
2.10	… policy units involved in the process of a Commission proposal					
2.11	… private sector and interest groups					
2.12	… other (please specify)					
	…					

		-2	-1	0	1	2
	3. Activities coordinated by the LIAISE community					
	The LIAISE community enhances the ability of my organisation in					
3.1	… doing research on impact assessment					
3.2	… offering services for impact assessment					
3.3	… implementing platforms for knowledge brokerage					
3.4	… doing impact assessment research transfer					
3.5	… other (please specify)					
	…					
	Within and without the LIAISE community my organisation is involved in type of activities as					
3.6	… research on the design of appraisal systems (improvement of methods, tools and processes)					
3.7	… research on the performance of appraisal systems (operations, compliance testing and support of policy development)					
3.8	… research on learning and evidence utilization in appraisal (institutional context, development over time)					
3.9	… research on the politics of appraisal (underlying motivations such as legitimacy or power)					
	My organisation has a special interest to maintain the following functions or services mentioned in the LIAISE Charter via the LIAISE community:					
3.10	… knowledge and information hub					
3.11	… networking and discussion forum					
3.12	… innovation and testing					
3.13	… tool identification and quality monitoring					
3.14	… shared learning and training courses					
3.15	… other (please specify)					
	…					

		-2	-1	0	1	2
	4. Activities identified by the Network of Excellence of LIAISE to improve impact assessment at European level					
	The LIAISE community aims to create value					
4.1	… within the research sector					
4.2	… within the policy units					
4.3	… within the private sector (consultants/business/interest groups)					
	The web platform of LIAISE KIT enhances the ability of my organisation to provide					
4.4	… tools, methods and research results for the toolbox					
4.5	… knowledge and research results for the shared research agenda					
4.6	… networking and information services					
4.7	… meta-data					
4.8	… procedural principles					
4.9	… quality guidelines					
4.10	… procedural guidelines and good practice examples					
4.11	… professional qualification (staff exchanges, training courses, etc)					
4.12	… other (please specify)					
	…					

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	The activities of the LIAISE community will have an enduring impact on					
4.13	… my organization					
4.14	… the policy units within the impact assessment system of the EU					
4.15	… the research community					
4.16	… other (please specify)					
	…					

		-2	**-1**	**0**	**1**	**2**
	5. Activities to strengthen different types of relationships within the LIAISE community					
5.1	The LIAISE community is a network of individual researchers					
5.2	The LIAISE community benefits my organisation by strengthening the intensity of relationships between individual researchers					
5.3	The LIAISE community is an institutional alliance between research organisations					
5.4	The LIAISE community benefits my organisation by strengthening the intensity of institutional relationships					
5.5	The LIAISE community is strengthened by other drivers (please specify)					
	…					
	The LIAISE community is valuable because due to it my organisation can better achieve relationship benefits such as					
5.6	… collaboration within the network					
5.7	… complementary activities					
5.8	… effectiveness and impact due to synchronisation					
5.9	… competitive advantages					
5.10	… synergies based on similarity					
5.11	… an alertness for opportunities by acquaintance					
5.12	… effectiveness in research collaboration by academic or geographic proximity					
5.13	… other (please specify)					
	…					
5.14	My personal motivation to strengthen relationships of the LIAISE community is bigger than that of my organisation?					

		-2	**-1**	**0**	**1**	**2**
	6. Commitments made by the LIAISE community to improve impact assessment as stated in the LIAISE Charter					
	Through the LIAISE community the research activities for impact assessment of my organisation will					
6.1	… gain more relevancy					
6.2	… gain more credibility					
6.3	… gain more legitimacy					
6.4	… gain more transparency					
6.5	… gain more contextualization					
6.6	… profit from the dialogue within the network					
6.7	… profit from the long-term and integrative aspects					

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6.8	… other (please specify)					
	…					
	My organisation most contributes to these commitments by providing resources as					
6.9	… direct advice					
6.10	… expertise via publications					
6.11	… monetary or in-kind contribution					
6.12	… communication and social exchange					
6.13	… technical support for researchers					
6.14	… other (please specify)					
	…					
	As a member of the LIAISE community at my organisation I expect a workload of ... (please indicate)					
6.15	… hours per month within the next 2 years	_____ hrs				
6.16	… hours per month within the next 3 to 5 years	_____ hrs				

		-2	**-1**	**0**	**1**	**2**
	7. Impact attributed to the performance of the LIAISE community					
	The LIAISE community generates additional value for my organisation					
7.1	… through commercialisation of research output					
7.2	… through communication of research output					
7.3	… by allowing better distribution mechanisms for costs and benefits in impact assessment research					
7.4	… by enhancing the ability of my organisation to create monetary revenues					
7.5	… by enhancing the ability of my organisation to create non-monetary revenues					
7.6	… other (please specify)					
	…					
	The LIAISE community is expected to					
7.7	… upgrade the quality of research for impact assessment that is produced by my organisation					
7.8	… upgrade the value and fit of research results for impact assessment					
7.9	… improve the transfer of knowledge from my organisation to transcend disciplinary and science-policy boundaries					
7.10	… improve the conducive environment for the concept of sustainable development in impact assessment					
7.11	… enhance the direct involvement of researchers from my organisation in the process of proposal development and impact assessment					
7.12	… other (please specify)					
	…					
	LIAISE enables my research organisation to better access funding bodies such as					
7.13	… research programmers and evaluators					
7.14	… funding agencies and donors					

7.15	… private sector organisations					
	… other (please specify)					
	…					

		-2	**-1**	**0**	**1**	**2**
	8. How to maintain the LIAISE community?					
	My organisation prefers to maintain the added value of LIAISE community activities via					
8.1	… a loose consortium that attracts funding to the partner organisations					
8.2	… individual contribution of my organisation					
8.3	… the instalment of a new entity with own funding strategies					
8.4	… other (please specify)					
	…					
8.5	From my position within the organisation I have authority to allocate funds to an entity					
	The utilisation of impact assessment research via the LIAISE community can be best maintained by					
8.6	… private sector funding					
8.7	… public sector funding					
8.8	… contracts with researchers					
8.9	… contracts with research organisations					
8.10	… project funds delegated to individual researchers					
8.11	… project funds delegated to project networks					
8.12	… project funds delegated to research alliances					
8.13	… other (please specify)					
8.14	The type and source of funding for maintaining the LIAISE activities will in the long term impact the quality of research					

9.	Please indicate years of experiences in the field of impact assessment for sustainable development of your organisation : _____________and yourself: ______________

10.	By reviewing the questionnaire you might have missed the opportunity to answer in your own words. We herewith kindly request you to address most important shortages of questions or to give general comments.

			n	sum	strength	interest	(+2)	(+1)	0	(-1)	(-2)	agree (%)	disagree (%)	RM	TE	CO	SE	RP
1. Coordinating Actor: Self-conception of the LIAISE community																		
The Network of Excellence of LIAISE coordinated multidisciplinary scientific cooperation for impact assessment		1.1	15	19	63,3	63,3	8	5	0	2	0	87	13	x				
The Network of Excellence of LIAISE coordinated research for the better integration of knowledge for impact assessment		1.2	15	23	76,7	76,7	9	5	1	0	0	93	0	x				
The LIAISE charter states several aspects of LIAISE output. My organisation has most contributed to	… economic aspects of policy impact assessment	1.3	15	-4	-13,3	13,3	3	3	1	3	5	40	53					
	… environmental aspects of policy impact assessment	1.4	15	16	53,3	53,3	8	3	2	1	1	73	13	x				
	… social aspects of policy impact assessment	1.5	14	-5	-17,9	17,9	1	5	0	4	4	43	57					
	… policy aspects of policy impact assessment	1.6	14	15	53,6	53,6	5	7	1	0	1	86	7	x				
	… the integration of different aspects of policy impact assessment	1.7	15	15	50,0	50,0	5	7	2	0	1	80	7	x				
	… other	1.8																
In future, my organisation expects to be represented by the LIAISE community for ensuring an efficient	… integration of economic aspects of impact assessment	1.9	14	2	7,1	7,1	3	5	1	1	4	57	36					
	… integration of environmental aspects of impact assessment	1.10	14	22	78,6	78,6	9	4	1	0	0	93	0	x				
	… integration of social aspects of impact assessment	1.11	14	0	0,0	0,0	2	6	0	2	4	57	43					
	… integration of policy aspects of impact assessment	1.12	14	18	64,3	64,3	7	5	1	1	0	86	7	x				
	… integration and transfer of knowledge for impact assessment	1.13	14	15	53,6	53,6	7	3	2	2	0	71	14	x				
	… other	1.14																
2. System Addressed: Target system of the LIAISE community																		
According to your own perception, the LIAISE community as it is described on its website aims to improve impact		2.1	14	21	75,0	75,0	9	3	2			86	0	x				
According to your own perception, the LIAISE community as it is described on its website aims to improve impact		2.2	14	11	39,3	39,3	3	7	3	0	1	71	7			x		x
The LIAISE community enhances the ability of my organisation to address	… consultants (researchers & private sector)	2.3	15	0	0,0	0,0	0	6	0	6	0	40	40					
	… scientific communities and research scientists and students	2.4	15	14	46,7	46,7	3	9	2	1	0	80	7					
	… policy units involved in the process of a Commission proposal	2.5	15	11	36,7	36,7	5	5	2	2	1	67	20					
	… private sector and interest groups	2.6	15	-8	-26,7	26,7	1	2	4	4	4	20	53					
	… other (please specify)	2.7																
To improve European Commission impact my organisation emphasises the need to strengthen the exchange with	… consultants (researchers & private sector)	2.8	15	-2	-6,7	6,7	0	1	9	4	0	13	27		x	x		x
	… scientific communities and research scientists and students	2.9	15	15	50,0	50,0	3	9	3	0	0	80	0	x				
	… policy units involved in the process of a Commission proposal	2.10	15	19	63,3	63,3	5	9	1	0	0	93	0	x				
	… private sector and interest groups	2.11	15	-1	-3,3	3,3	1	4	5	3	2	33	33			x		x
3. Activities subject to coordination: Activities coordinated by the LIAISE community																		
The LIAISE community enhances the ability of my organisation in	… doing research on impact assessment	3.1	15	13	43,3	43,3	6	5	1	2	1	73	20					
	… offering services for impact assessment	3.2	15	6	20,0	20,0	2	5	5	3	0	47	20					
	… implementing platforms for knowledge brokerage	3.3	15	10	33,3	33,3	3	7	2	3	0	67	20					
	… doing impact assessment research transfer	3.4	14	7	25,0	25,0	3	5	3	2	1	57	21					
	… other (please specify)	3.5																
Within and without the LIAISE community my organisation is involved in type of activities as	… research on the design of appraisal systems (improvement of methods, tools and processes)	3.6	15	15	50,0	50,0	7	5	0	2	1	80	20	x				
	… research on the performance of appraisal systems (operations, compliance testing and support of policy development)	3.7	15	3	10,0	10,0	3	4	3	3	2	47	33					
	… research on learning and evidence utilization in appraisal (institutional context, development over time)	3.8	15	7	23,3	23,3	1	9	2	2	1	67	20					
	… research on the politics of appraisal (underlying motivations such as legitimacy or power)	3.9	15	1	3,3	3,3	4	4	0	3	4	53	47					
My organisation has a special interest to maintain the following functions or services mentioned in the LIAISE Charter via the LIAISE community:	… knowledge and information hub	3.10	15	19	63,3	63,3	6	8	0	1	0	93	7	x				
	… networking and discussion forum	3.11	15	26	86,7	86,7	11	4	0	0	0	100	0	x				
	… innovation and testing	3.12	15	8	26,7	26,7	3	6	3	2	1	60	20			x		
	… tool identification and quality monitoring	3.13	15	8	26,7	26,7	3	7	2	1	2	67	20				x	x
	… shared learning and training courses	3.14	15	9	30,0	30,0	2	9	1	2	1	73	20		x			
	… other (please specify)	3.15																
4. Interventions taken: Activities identified by the Network of Excellence of LIAISE to improve impact assessment at European level																		
The LIAISE community aims to create value	… within the research sector	4.1	15	21	70,0	70,0	8	6	0	1	0	93	7	x				
	… within the policy units	4.2	15	16	53,3	53,3	5	8	0	2	0	87	13	x				
	… within the private sector (consultants/business/interest groups)	4.3	15	-3	-10,0	10,0	1	2	7	3	2	20	33		x	x		
The web platform of LIAISE KIT enhances the ability of my organisation to provide	… tools, methods and research results for the toolbox	4.4	15	15	50,0	50,0	6	6	1	1	1	80	13	x				
	… knowledge and research results for the shared research agenda	4.5	15	6	20,0	20,0	2	6	4	3	1	53	20					
	… networking and information services	4.6	15	13	43,3	43,3	4	7	2	2	0	73	13					
	… meta-data	4.7	15	2	6,7	6,7	1	4	7	2	1	33	20					
	… procedural principles	4.8	15	0	0,0	0,0	1	5	4	3	2	40	33					
	… quality guidelines	4.9	15	-1	-3,3	3,3	0	6	4	3	2	40	33					
	… procedural guidelines and good practice examples	4.10	15	9	30,0	30,0	4	6	2	1	2	67	20					
	… professional qualification (staff exchanges, training courses, etc)	4.11	15	5	16,7	16,7	3	3	6	2	1	40	20					
	… other (please specify)	4.12																
The activities of the LIAISE community will have an enduring impact on	… my organization	4.13	15	4	13,3	13,3	2	5	5	1	2	47	20					
	… the policy units within the impact assessment system of the EU	4.14	15	4	13,3	13,3	2	4	6	2	1	40	20					
	… the research community	4.15	15	11	36,7	36,7	3	7	4	0	1	67	7					
	… other (please specify)	4.16																

5. Types of relationships: Activities to strengthen different types of relationships within the LIAISE community																		
The LIAISE community is a network of individual researchers		5.1	15	15	50,0	50,0	6	5	2	2	0	73	13	x				
The LIAISE community benefits my organisation by strengthening the intensity of relationships between individual		5.2	15	13	43,3	43,3	3	9	1	2	0	80	13		x		x	
The LIAISE community is an institutional alliance between research organisations		5.3	15	9	30,0	30,0	3	6	3	3	0	60	20					
The LIAISE community benefits my organisation by strengthening the intensity of institutional relationships		5.4	15	6	20,0	20,0	2	6	3	4	0	53	27		x			x
The LIAISE community is strengthened by other drivers (please specify)		5.5																
The LIAISE community is valuable because	… collaboration within the network	5.6	15	14	46,7	46,7	3	10	0	2	0	87	13					
due to it my organisation can better achieve	… complementary activities	5.7	15	13	43,3	43,3	4	7	2	2	0	73	13					
relationship benefits such as	… effectiveness and impact due to synchronisation	5.8	15	-2	-6,7	6,7	0	5	5	3	2	33	33					
	… competitive advantages	5.9	15	4	13,3	13,3	1	6	5	2	1	47	20					
	… synergies based on similarity	5.10	15	6	20,0	20,0	2	6	4	2	1	53	20					
	… an alertness for opportunities by acquaintance	5.11	15	2	6,7	6,7	1	7	1	5	1	53	40					
	… effectiveness in research collaboration by academic or geographic proximity	5.12	15	5	16,7	16,7	3	6	1	3	2	60	33					
	… other (please specify)	5.13																
My personal motivation to strengthen relationships of the LIAISE community is bigger than that of my organisation?		5.14	13	8	30,8	30,8	2	7	2	1	1	70	15					
6. Mechanism for effectiveness: Commitments made by the LIAISE community to improve impact assessment as stated in the LIAISE Charter																		
Through the LIAISE community the research	… gain more relevancy	6.1	15	5	16,7	16,7	2	5	4	4	0	47	27					
activities	… gain more credibility	6.2	15	7	23,3	23,3	2	6	4	3	0	53	20					
for impact assessment of my organisation will	… gain more legitimacy	6.3	15	2	6,7	6,7	1	4	6	4	0	33	27					
	… gain more transparency	6.4	15	3	10,0	10,0	0	8	3	3	1	53	27					
	… gain more contextualization	6.5	14	4	14,3	14,3	2	5	2	5	0	50	36					
	… profit from the dialogue within the network	6.6	15	16	53,3	53,3	4	9	1	1	0	87	7	x				
	… profit from the long-term and integrative aspects	6.7	15	13	43,3	43,3	4	6	4	1	0	67	7					
	… other (please specify)	6.8																
My organisation most contributes to these	… direct advice	6.9	15	9	30,0	30,0	1	9	3	2	0	67	13		x	x		
commitments by providing resources as	… expertise via publications	6.10	15	18	60,0	60,0	6	6	3	0	0	80	0	x				
	… monetary or in-kind contribution	6.11	14	-2	-7,1	7,1	2	3	3	3	3	36	43				x	x
	… communication and social exchange	6.12	14	9	32,1	32,1	2	8	2	1	1	71	14				x	x
	… technical support for researchers	6.13	15	2	6,7	6,7	0	5	7	3	0	33	20		x	x		
	… other (please specify)	6.14																
As a member of the LIAISE community at my	… hours per month within the next 2 years	6.15	12	71 hours														
organisation I expect a workload of … (please	… hours per month within the next 3 to 5 years	6.16	9	42 hours														
7. Performance aimed at: Impact attributed to the performance of the LIAISE community																		
The LIAISE community generates additional	… through commercialisation of research output	7.1	15	-11	-36,7	36,7	0	2	4	5	4	13	60		x	x		
value for my organisation	… through communication of research output	7.2	15	13	43,3	43,3	3	7	5	0	0	67	0				x	x
	… by allowing better distribution mechanisms for costs and benefits in impact assessment research	7.3	15	-3	-10,0	10,0	0	4	6	3	2	27	33					
	… by enhancing the ability of my organisation to create monetary revenues	7.4	15	-12	-40,0	40,0	0	2	4	4	5	13	60					
	… by enhancing the ability of my organisation to create non-monetary revenues	7.5	15	5	16,7	16,7	1	8	2	3	1	60	27					
	… other (please specify)	7.6																
The LIAISE community is expected to	… upgrade the quality of research for impact assessment that is produced by my organisation	7.7	15	3	10,0	10,0	1	5	6	2	1	40	20				x	
	… upgrade the value and fit of research results for impact assessment	7.8	15	7	23,3	23,3	1	8	3	3	0	60	20		x			
	… improve the transfer of knowledge from my organisation to transcend disciplinary and science-policy boundaries	7.9	15	10	33,3	33,3	1	9	4	1	0	67	7			x		
	… improve the conducive environment for the concept of sustainable development in impact assessment	7.10	15	7	23,3	23,3	1	8	3	3	0	60	20					x
	… enhance the direct involvement of researchers from my organisation in the process of proposal development and impact assessment	7.11	15	12	40,0	40,0	4	7	2	1	1	73	13					
	… other (please specify)	7.12																
LIAISE enables my research organisation to	… research programmers and evaluators	7.13	15	8	26,7	26,7	1	9	3	1	1	67	13					
better access funding bodies such as	… funding agencies and donors	7.14	15	7	23,3	23,3	1	7	5	2	0	53	13					
	… private sector organisations	7.15	15	-8	-26,7	26,7	0	2	6	4	3	13	47					
	… other (please specify)	7.16																
8. Sources of revenue: How to maintain the LIAISE community?																		
My organisation prefers to maintain the	… a loose consortium that attracts funding to the partner organisations	8.1	15	10	33,3	33,3	5	5	2	1	2	67	20					
added value of LIAISE community activities	… individual contribution of my organisation	8.2	15	4	13,3	13,3	1	8	2	2	2	60	27					
via	… the instalment of a new entity with own funding strategies	8.3	15	-8	-26,7	26,7	1	3	3	3	5	27	53					
	… other (please specify)	8.4																
From my position within the organisation I have authority to allocate funds to an entity		8.5	15	-11	-36,7	36,7	0	3	4	2	6	20	53					
The utilisation of impact assessment research	… private sector funding	8.6	14	-11	-39,3	39,3	0	1	4	6	3	7	64		x	x		
via the LIAISE community	… public sector funding	8.7	15	17	56,7	56,7	3	11	1	0	0	93	0	x				
can be best maintained by	… contracts with researchers	8.8	14	1	3,6	3,6	1	6	2	3	2	50	36		x	x		

… contracts with research organisations	8.9	15	8	26,7	26,7	3	6	3	2	1	60	20				x	x
… project funds delegated to individual researchers	8.10	15	7	23,3	23,3	1	8	4	1	1	60	13		x	x		
… project funds delegated to project networks	8.11	15	11	36,7	36,7	3	8	2	1	1	73	13				x	
… project funds delegated to research alliances	8.12	15	10	33,3	33,3	4	5	4	1	1	60	13					x
… other (please specify)	8.13																
The type and source of funding for maintaining the LIAISE activities will in the long term impact the quality of research	8.14	12	9	37,5	37,5	2	6	3	1	0	67	8					
Please indicate years of experiences in the field of impact assessment for sustainable development of your organisation:	9.1	13	213 years														
Please indicate years of experiences in the field of impact assessment for sustainable development of yourself:	9.2	13	138 years														
By reviewing the questionnaire you might have missed the opportunity to answer in your own words. We herewith kindly	10.																

n = number of respondents
sum = Sum of Likert points
strength = sum of Likert points in percentage related to the potential Likert points (-30 to +30)
interest = absolute sum of Likert points in percentage related to the potential Likert points (0 to +30)
Likert scale: strongly agree (+2), agree (+1), neutral (0), disagree (-1), strongly disagree(-2)
agree = percentage number of respondents with positive response in relation to total number of respondents
disagree = percentage number of respondents with negative response in relation to total number of respondents

EI: questions with enhanced interest (i >47%)
TE: questions related to a model profile for training and education
CO: questions related to a model profile for consultancy
SE: questions related to a model profile for scientific exchange
RP: questions related to a model profile for research programming

SECTION III

Section III analyses the governance level of an innovation process in the Triple Helix System of Innovation for Sustainability (THIS). The governance level is analysed using one case study.

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Should the ecosystem services concept be used in European Commission impact assessment?

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ABSTRACT

Integrated impact assessment (IA) of policies in the European Commission takes place in an environment of competing problem frames, contested policy objectives and a multitude of interested actors. This paper sets out to discuss the potential value of integrating the ecosystem services (ESS) concept for improving the consideration of environmental benefits and values during framing and appraisal of new policies at European level. The discussion was based on a workshop conducted with experts encompassing their disciplinary fields to the science–policy interface. A review of recent literature and impact assessment reports from policy science and ecosystem services research allowed for a two-way contemplation. The potential integration of concepts was analysed for conceptual, technical, ethical and pragmatic aspects. It was found that indicator sets applied in the impact assessment reports follow a much less formalised structure than the reports or the procedure. An integration of the ecosystem services concept would enhance the requisite variety of indicators used, and thus contribute to the overall goal for sustainable development. Potentials for improving IA lie particularly in the up- and downscaling of benefits and values, policy relevant comparative studies and the prospective possibilities for innovation in indicator development. Based on this rationale of improving requisite variety for future decision making, the emphasis lies on a further development of the ESS concept along two pathways of operationalisation: the translation of the concept for a comprehensive approach at a higher level of abstraction (soft application), and the application of the concept for providing aggregated, quantitative and unit-based information at different steps of an IA (hard application).

> Les uns ont, ce me semble, beaucoup d'instruments et peu d'idées; les autres ont beaucoup d'idées et n'ont point d'instruments.
> Denis Diderot (1713–1784). De l'interprétation de la nature.

1. Introduction

Sustainability may be a critical concept, but it seems likely to abide as long as real problems demand attention to intertwined socio-economic, political and biophysical considerations in a long-term planning perspective (Gibson, 2006). The concern articulated in policy planning is that current strategies for sustainable development do not decelerate the depletion of natural resources, and that the time has come to consider structural changes in governance (OECD, 2012; Biermann et al., 2012). Implementation deficits can be ascribed to the sectoral organisation of government (Jacob and Volkery, 2004), use of knowledge in hierarchical governance arrangements (Atkinson and Klausen, 2011), the neglect of needs of future generations or a dominance of short termism (Siebenhüner et al., 2013).

The consideration of environmental issues requires a routine and systematic check of policies of all sectors. The commitment to evidence-based policy making is considered one approach to enable the consideration of side effects on the environment early on in the process, and provide legitimacy to policy makers (Hertin et al., 2008). However, while it is argued that there are enough scientifically sound indicators (e.g. Jesinghaus, 2012; Von Stackelberg, 2013) an assessment regime that is applicable to a broad range of political undertakings is missing (Hertin et al., 2009).

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It is argued that the ecosystem services concept as described in the Millennium Ecosystem Assessment (MEA, 2005) is one scientifically respected framework capturing environmental concerns in ecological and socio-economic terms (Braat and de Groot, 2012; TEEB, 2009, 2010). Ecosystem services (ESS) are defined as the contributions of ecosystem structure and function to human well-being. ESS and the natural assets that produce them, represent a significant contribution to sustainable development that is increasingly recognised (Burkhard et al., 2012a).

Much of today's ESS science and the framework's further development for decision making is based on works done in the MEA that was called for by the United Nations in 2000 and was supported by 1360 experts from 95 countries (MEA, 2005). It had the overarching goal to synthesise information about the environmental status and trends, as well as the dependence of human well-being on natural capital, ecosystems and the services they provide. The ESS concept has since contributed to overall policy strategies such as the EU Biodiversity strategy to 2020, the EU Habitats Directive and the EU Blueprint to safeguard Europe's Waters. Strengths of the ESS framework are seen in cross-sector cooperation and the handling of ESS trade-offs and synergies at a landscape level, in the integrative character of the concept across environmental compartments, and in its applicability in communication processes as well as stakeholder-oriented valuation and weighting (Burkhard et al., 2012a; Geneletti, 2011). Eppink et al. (2012) describe the potential asset in policy design in addressing welfare gains and losses, but highlight the need for a common assessment framework with comparable data sets. Maes et al. (2013) ascertain that including the ESS concept into all social and economic policies would allow for a systematic review of consequences beyond conventional environmental assessments. This development calls for a debate on the incorporation of the ESS concept into effective and enduring institutions to manage and monitor the societal values of ecosystem services.

The European Commission policy impact assessment (IA) is a requirement for all major policy initiatives and therefore appears as a promising venue for an incorporation of ESS into decision making. Its intention is to consider all major impacts of planned policies on economy, environment and social aspects in order to maximise the benefits and minimise unwanted side effects. Furthermore, it is considered as an approach to ensure the coherence of policies with the overarching strategies of the European institutions.

During the past ten years, the relevance of IA has increased considerably: Commission directorates have set up support units, while consultants and researchers have been awarded framework contracts for supportive action, and training courses for officers have been developed. Furthermore, the process has been reviewed and evaluated. The Joint Research Centre (JRC) of the European Commission has set up a modelling group for IAs and a number of projects have been funded to develop models and data formats for the specific context of IA (Podhora et al., 2013; Radaelli and Meuwese, 2010; Lee and Kirkpatrick, 2006). As a result of this capacity development and learning, IA of policies has gained in terms of quality of the analysis and increased in importance for the decision making process. While the economic parts of the assessments were found to have improved over the years (Cecot et al., 2008), environmental impacts and benefits from environmental protection are still considered undervalued, particularly from the viewpoint of nature conservation (Jacob et al., 2011). Problems of data availability and stakeholder opinion remain, in particular for those impact areas that do not have an explicit market value, such as biodiversity or climate change (EC, 2013).

The overall question is, whether the ESS concept can be conceptually and technically integrated into European Commission impact assessment procedures at an operational level (van Wensem and Maltby, 2013; Jordan and Russel, 2014; Dunbar et al., 2013). A workshop conducted in Vigoni, Italy in October 2012 presented an opportunity to bring together scientific experts that encompassed their disciplinary field of research to address the interface with European level decision-making and decision support. The aim was to reach a deeper understanding of the potentials of an integration of ESS indicators in the decision making process by taking a dual perspective from policy sciences and environmental ecosystem research.

The objective of this paper is to take a forward looking perspective to reflect whether the concept of ESS should be used in European policy IA. Based on the workshop discussion, a review of the procedure and outcome of recent assessment reports as well as current literature addressing the link between ESS and decision making on the European level, the following questions will be addressed:

- Is the EC *ex ante* impact assessment procedure a suitable instrument to integrate the ESS concept?
- Can the ESS concept comply with the requirements and demands of an actual European impact assessment process in order to be operational?

By analysing the requirements of IA towards qualifying the process as suitable for an integration of the ESS concept, we aim to contribute to the ongoing discussion in the ESS research community on the potentials of the concept to "deliver" (Daily et al., 2009) at a European level of decision making.

2. The European Commission policy impact assessment process

Integrated policy impact assessment (IA) was introduced by the European Commission in 2003 to be conducted for all policy proposals as an obligatory activity in the EU legislative procedure *ex ante* actual implementation (EC, 2002). Motivated by an action plan for better regulation standards in 2001, the European Commission was determined to employ new instruments within the policymaking process in order to achieve the policy goals set down in the Lisbon agenda (Renda, 2006; Mandelkern Report, 2011). At the same time, the European Council agreed on the implementation of a European strategy for sustainable development (Göteborg European Council, 2001). An integrated assessment was to contribute to sustainable development by considering and comparing economic, social and environmental aspects for a set of strategic policy options during the formulation of new regulations.

The introduction of IA replaced a number of specific requirements for policy assessment in terms of environmental impacts, health or the competitiveness of small and medium enterprises. The development of one single and integrated procedure was to give the process more relevance at the political level, to avoid unnecessary additional burdens for policy makers, and to allow for an analysis of potential trade-offs between impact dimensions.

Planning of an IA in the Commission starts at an early stage of policy formulation. As soon as a policy initiative is published in the Commission's work program, the responsible policy unit initiates the IA. The Commission's guidelines for IA suggest inviting other Commission services to an inter-service steering committee if impacts can be expected in the domains of other directorates. Furthermore, it is a requirement to consult with stakeholders throughout the process. Thereby, the analysis should take into account all relevant aspects. A draft document is first reviewed by the Impact Assessment Board (IAB), composed of senior officers from various directorates. The IAB makes suggestions for including additional aspects or methodological improvements in the analysis. The IA report is then published together with the policy proposal and the opinion of the IAB before the proposal is submitted to other European institutions, parliament and council to allow for public scrutiny (Radaelli and Meuwese, 2010).

The IA analysis of the European Commission addresses the following aspects: definition of the problem, description of the objectives, identification of policy options to achieve the objective, assessment of relevant economic social and environmental impacts of each option, and the comparison of options. The IA guidelines provide a set of impact areas covering the economic, societal and environmental impacts including guiding questions for their analysis (EC, 2009).

While the guidelines suggest a structured and systematic approach, IA takes place in a highly politicised context of policy making. What is considered as relevant for analysis and the justification of a policy depends on the world views and norms of the actors involved. IA is frequently considered as a process which merely justifies what has already been decided rather than an open learning (e.g. Turnpenny et al., 2008; Nilsson et al., 2008). It is suspected to put emphasis on economic analysis and the determination of costs for business, while social and environmental aspects are not always considered in sufficient detail (European Court of Auditors, 2010).

From a perspective of interaction between actors involved in the preparation of a policy proposal and an IA, the IA process can be split into three steps which can be distinguished by the purpose of communication: (i) framing of the objectives, stakeholder dialogue and data gathering, (ii) internal scrutiny of the report for consistency and evidence, and (iii) negotiation of the policy proposal by drawing on the impact assessment report and further substantiating assessment documents if appropriate (EU Smart Regulation, 2015). The first and last steps cross the boundaries of the Commission to the public, while the second step remains an inter-institutional interaction. The first two steps have in common that they are defined by analytical preparation work, whereas the third phase is defined by policy implementation. For practical reasons it may be added that the addressees for an actively initiated knowledge transfer differ according to the stage of proposal development. Stakeholder dialogue and data analysis are conducted under the responsibility of the leading policy unit and the interservice steering group, while the identification of scenario impacts and trade-offs are steered by policy actors, stakeholder groups and consultants involved in the process. The evaluation of impacts against societal and political paradigms and the political negotiation process is defined by the European Parliament, national EU member state parliaments as well as the Council of Ministers.

In such a setting of many different actors, viewpoints, values and expectations regarding a policy and the related IA, an adequate consideration of environmental impacts is prone to being neglected. The case of the biofuels directive serves as an example for an IA where indirect impacts on land use were not considered in sufficient detail although knowledge would have been available. Such examples pose questions of credibility and cause stakeholders to suspect merely symbolic and legitimising activities. IAs may then be challenged by stakeholders producing own assessments and counter expertise as it was the case in the European Chemical legislation REACH. In this case, more than 40 assessment reports were produced by industry associations, member states, regions and environmentalists, thereby triggering a battle of impact assessments (Jacob and Volkery, 2005).

The challenge within this setting of competing actors and interests lies in the need to focus on relevant aspects, and in the uncertainty and frequent ambiguity of scientific knowledge in the context of decisions. Based on the argument that integration and deliberation are at the core of the sustainability concept, assessment procedures at all stages require the consideration of a multitude of methods and tools adapted to the decision process (Bond and Morrison-Saunders, 2011; Gibson, 2006). Against this background we explore in what way the concept of ESS can provide substantiation for a robust and accepted IA that considers environmental aspects in an improved quality.

3. Methods

The study presented in this paper was framed in an international interdisciplinary workshop in Vigoni, Italy in October 2012. The participating experts were identified based on previous research on the development of methods and models for European Commission IA (Podhora et al., 2013), contribution to scientific conferences and literature, cooperation in impact assessment projects at European level and personal recommendations. The workshop was structured by three discussion rounds that addressed the specifications and nature of the science–policy interface during the IA process, the factors that may hinder and the requirements that may achieve an integration of the ESS concept in IA.

Building upon the questions raised in the workshop, this paper combines the scientific discussion on ecosystem services (identified in a literature survey) with the analysis of its application in IA (based on document analysis) (Fig. 1).

3.1. Literature survey

A literature review was conducted for the recent literature published by the initial round of experts in the different research traditions and scientific disciplines of ecology, economy and social sciences. It was complemented by electronic searching of scientific databases for research conducted on the conceptual, theoretical, methodological and instrumental use of the ESS concept in a European decision making context (Web of Science, Science Direct). We particularly focused review articles, representative studies and discussion papers (172 articles selected; 23 articles specifically addressing an integration of ESS for a European assessment). The choice of documents was led by the following criteria:

- The research is part of either ESS research or IA research,
- The research addresses the integration of environmental, societal and economic aspects of sustainability,
- The research contributes to policy integration and decision making.

3.2. Document analysis

For an illustration of current practice in the application of ESS indicators in European Commission IAs, we reviewed all 57 IA reports published in 2014. The aim was to further inform the discussion on the type and nature of indicator data taken up by the policy

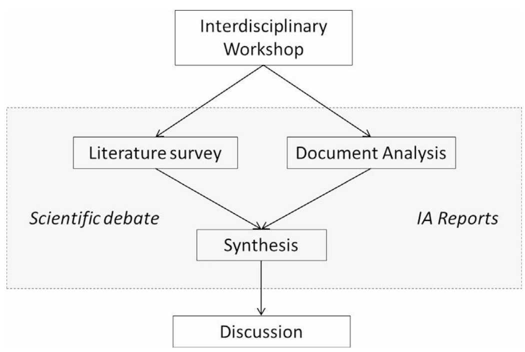

Fig. 1. Overview on sources and approach.

sector. For an assessment of the degree of embedding environmental considerations in the IA reports, we followed the classification proposed by Turnpenny et al. (2014). The classification ranges from no ecological or environmental knowledge referred to (0) over environmental assessment (environment mentioned (1), mentioned but weakly evaluated (2), strong environmental framing but not ecosystem services (3)) up to explicit assessment of ESS (framing around ESS (4), ESS fully embedded in the assessment (5)). We further distinguished whether the policy for which the impact assessment was conducted explicates environmental objectives and whether the described impacts have an implicit or explicit spatial dimension (Helming et al., 2013).

The focus on recent literature as well as the most recent IA reports (all reports published in 2014) is rooted in the understanding that ESS integration has only in recent years moved into the focus of European policy formulation and has considerably gained since.

3.3. Synthesis

The synthesis brings together results from the scientific debate and the analysis of current practice documented in the impact assessment reports (Fig. 1). We followed a practical approach for the appraisal of policy innovations in terms of conceptual, ethical, technical and pragmatic aspects as described by Lee (1999). This approach was adapted by rephrasing the questions from an *ex post* perspective to discuss the prospective potential of ESS to facilitate environmental policy integration in future IAs. Critical appraisal was conducted by grouping comparable studies together and extracting the key results along the following four questions:

- Does conceptual integration of the ESS concept into IA make sense?
- What could be potential benefits or misfits?
- What available evidence suggests that the (theoretical) idea of integration can be translated into practice?
- What evidence available proves prospective “fit-for-purpose”?

The methodology was chosen based on recommendations given by Pawson et al. (2005) for realist review approach and Greenhalgh et al. (2005) on systematic review using meta-narrative analysis. Initially designed for rapid reviews in decision support, a descriptive approach was found favourable particularly in cases characterised by a diversity of research approaches and the impossibility to structure initial findings into a single theoretical taxonomy. In this study, the methodology allowed for taking a stand in between policy research and ESS science, in order to discuss the potential integration of concepts with a perspective into both directions.

4. Results

Although the ESS concept is increasingly considered a viable tool for environmental integration in policy formulation within the scientific community, the documented IA reports draw a more differentiated picture. Overall, the application of indicator sets in the impact assessment procedure is far less formalised than the structure and standardisation of the process itself. A large variety of single and aggregated indicators is used, and there is no indication for a usable definite set of indicators available that fits all policy appraisals. The following sections will illustrate the results from the literature survey, the document analysis and the synthesis.

4.1. Literature review

Potentials for an integration of the ESS concept into European IA are seen in the illustration of direct and indirect sector impacts and in the development and application of ecosystem-based indicators (Helming et al., 2013; Maes et al., 2012). Sets of ESS indicators that are applicable on multiple levels of aggregation from the local to the global scale were provided (e.g. CICES; Haines-Young and Potschin, 2013). Mapping of biodiversity and various ESS on large areas across the European Union (Maes et al., 2012) or global estimates of the value of biomes (De Groot et al., 2012) have been tested next to the up-scaling of information from well-chosen in-depth case studies (Paracchini et al., 2011). Local subsets within an assessment matrix require expert-based integration of knowledge at local levels by attaining useful data from those that know their environment best (Jacobs et al., 2015), with the benefit of bringing out normative variations in valuation (Stoll et al., 2015; Dick et al., 2014). The general framing of ESS assessments was found useful for various types of decision in policy development, e.g. as a decisive tool for structuring participation and analysis, as a technical instrument for substantiation, or as an informative contribution to discussions (Apitz, 2013). In principle, this interpretation matches all three possible entry points for interaction and communication in the IA process described previously.

Contextual requirements due to different target groups at the science–policy interface are highlighted by the majority of authors. Practicalities, such as different potential target groups for interaction within one single assessment process, are not explicitly described in the reviewed literature. It was discussed, however, that the scientific community in particular is not sufficiently aware of the IA procedure in their model development. For a better integration, research framing would need to take into account the interface requirements between research and policy (e.g. Apitz, 2013; Matzdorf and Meyer, 2014; Anton et al., 2010). Beyond an adaption of technical language and improved awareness for sector targets, this would imply also a continuing confrontation with the link between environmental and societal impacts as well as improved approaches that translate feedback from valuation studies to the public and private sectors.

Improvements in attaining knowledge and understanding for informed decision making in IA was found to be discussed along two different lines of argumentation. Both address the points mentioned in Table 1, albeit at a different conceptual level.

I. The ecosystem services concept can aid a comprehensive assessment by structuring information for decision makers on the impact of framework legislations or policies. We suggest classifying this as the *soft application* of the ESS concept. This implies the assessment of the state and performance of ecosystem functionality to deliver ESS from a holistic perspective by building upon the existing variety of methods and approaches at different levels of scale and complexity, and for various types of decision support. Along this line of argument, requirements for better applicability are seen in the transparency of the ESS concept itself, in the communication of complex issues for integration and the development of management frameworks for a translation of the concept to specific decision making contexts (e.g. Matzdorf and Meyer, 2014; Apitz, 2013).

II. The ESS concept can be applied to quantify and monetise the benefits from functioning ecosystems from an anthropocentric socio-economic perspective. We suggest classifying this as the *hard application* of ESS. This implies providing quantitative and unit-based information about the impacts of human action on the functionality of for example service providing units (SPUs) and resulting changes in ESS delivery. Requirements for better

Table 1
Integrating ecosystem services with the EU policy impact assessment.

Arguments put forward in the scientific debate	Exemplary studies
Where can the ESS concept improve the impact assessment process?	
• Visualisation of existing data and trade-offs from different perspectives by using different filters • Translation of conservation necessities into sector policies • Communication of economic incentives for conservation planning and assessment • Application in diverse assessment approaches by matching targeted indicators to different levels of abstraction • Underpinning of argumentation for future benefits • Differentiation between problem-oriented research needs (need to act) and solution-oriented research needs (development of options)	Anton et al., 2010 Dunbar et al., 2013 Baker et al., 2013 Helming et al., 2013 Apitz, 2013 Jacob et al., 2013 Maes et al., 2013 Podhora et al., 2013 Matzdorf and Meyer, 2014
What factors may hinder the integration?	
• Relation to the European Commission targets (competition, better regulation and innovation) • Handling of technical and thematic uncertainties, particularly in relation to scales • Uncertainties in relation to land use and biodiversity • Limited experience with taking up accounting schemes; completion of accounting schemes • Description of the concept in a generic way to allow uptake in different assessment schemes • Clarification of responsibilities for implementation, measurement and monitoring of indicator mapping • Clarification as to which sectors need an integrated and which need a focused approach	Hou et al., 2013 Schägner et al., 2013 Laurans et al., 2013 Zulian et al., 2013 Dick et al., 2014
What requirements can achieve integration?	
• Consistent frameworks • Common language (versus technical language) • Common targets (versus economic or sector targets) • Action research for understanding of context • Integrity and linkage between basic science, applied science and implementation • Protocols and documentation for transparency • Adaptation to each given frame of scaling and legitimisation • Integration of the perception of stakeholders in the framing of scales • Handling of ESS valuation as a normative concept with a utilisation focus (also in regard to risks for crash or crisis)	Willems and de Lange, 2007 Paracchini et al., 2011 Maes et al., 2012 Von Stackelberg, 2013 Bertram and Rehdanz, 2013 Paracchini et al., 2014 Stoll et al., 2015 Laurans and Mermet, 2014; Everard et al., 2014

applicability are seen in standardisation of indicators, harmonisation of measurements at each scale and the development of interfaces between models for comprehensive assessments (e.g. Maes et al., 2012; Stoll et al., 2015).

One challenge of using data in an IA is due to the transparency of the IA reports. Policy officers appear to prefer sound scientific evidence which is unlikely to be challenged by stakeholder groups. In consequence, technical and methodological variances and quantitative uncertainties due to differences in units and scales applied in ESS studies are one major concern articulated from the policy side (Anton et al., 2010). Accordingly, this can lead to non-robust and ambiguous results, particularly in regard to valuation, monetisation or discounting. Hou et al. (2013) describe uncertainties in relation to landscape and ESS analyses and recommend that management strategies and learning cycles have to take account of uncertainty within the course of policy judgments. Laurans et al. (2013), however, point out that while ecosystem valuation studies address a number of technical, decisive and informative use cases for decision making, there is a blindspot in the literature regarding actual use practice.

Comparative studies between regions, between sets of experts at different decision making levels, or time frames give indications of uncertainties and scale-related deviations as long as the same set of indicators is used (Dick et al., 2014; Hou et al., 2013). Furthermore, Schägner et al. (2013) show that ESS studies are distributed evenly between local, regional, supra-regional and large-scale global studies, with most results presented in adherence to political borders. The application of the ESS concept to assess the effects of policies allows for a better understanding of the spatial distribution of such effects, and of the related issues of equity and conflict (Maes et al., 2012). This requires a case-specific display of relevant constituents to support the societal well-being and resilience for future well-being among different regions and also between different stakeholder groups.

Policy applications of ESS valuation have been tested for green accounting, land use policy evaluation, resource allocation and payments for ESS (Schägner et al., 2013). Existing studies are based on validated and non-validated as well as implicit models and require a high level of interdisciplinary integration. When applied in the communication about recent, past or potential future states of human-environmental systems, ESS indicators can identify gaps and trends to inform sustainable use in a policy-relevant representation. Problems of accuracy and precision, however, remain where an illustration of biological responses at different levels of organisation to ecosystem service delivery is required in a quantitative and predictive manner (e.g. alterations in biodiversity). One recent key action related to the EU Biodiversity Strategy to 2020 is the “Mapping and Assessment of Ecosystems and their Services in Europe” (MAES) initiative. The PRESS initiative (PEER Research on ESS) contributed case studies to help explore how such assessments for European policies might be developed (Maes et al., 2013). Results show that the inclusion of ESS indicators into policies would require a comprehensive effort for large-scale systematic review of indicator development and documentation of the consequences to achieve an improvement beyond conventional environmental assessments.

4.2. Analysis of IA reports

The majority of European Commission IA reports published in 2014 was conducted on governance measures such as subsidisation, risk prevention and market regulation. The objectives stated in the reports largely concerned competitive aspects (e.g. merger control), protective measures (e.g. organisation of working time), reporting (e.g. labelling of products or reporting on market transactions) or targeted support (e.g. state aid to reach strategic targets).

Environmental objectives were explicitly stated in 23 of the 57 IA reports screened. To a large extent, however, the environmental objectives had no direct relation to ecosystems. This was for example the case where ecodesigns of manufactured goods or emission regulations were targeted. Where the environmental objective was related to reporting, the policy objective may eventually have a significant impact on ecosystems. This was for example the case in the report on calculation methods and reporting requirements related to the quality of petrol and diesel requirements, and in the list of sectors and subsectors which are deemed to be exposed to a significant risk of carbon leakage for the period 2015–2019. Although these reports stated impacts regarding indirect land use change, air pollution and biodiversity as well as monetarised expressions of carbon leakage, the level of abstraction raises questions as to whether an integration of a full ESS-based assessment can be taken into account. In particular, since criteria and thresholds of regulations were in these cases laid out previously in respective directives.

For a better understanding, the IA reports were therefore also screened for their explicit or implicit spatial relevance. We found that of 57 IA reports, 9 reports explicitly addressed ecosystem-related issues (e.g. exploration of hydrocarbons such as shale gas, or the multi-annual planning of fish catch). 15 reports had an implicit spatial relevance, either at a concrete market level (e.g. labelling of products) or at a framework level (e.g. policy framework for climate and energy in the period from 2020 to 2030).

The impact section of all reports described economic, social and environmental impacts in separate chapters, thereby following the IA guidelines of the European Commission. Environmental impacts were described at different levels of elaboration in 28 of the 57 screened reports. Three reports focused environmental impacts including ESS and gave details in respect to the analysis (the policy framework on climate and energy, the Blue Energy Action Plan on the potential of ocean energy, the proposal for a regulation of the prohibition of driftnet fisheries). However, only the latter report explicitly stated an ecosystem-based framing. Furthermore, all three reports mention limitations in data and data aggregation, particularly for assessing biodiversity and land use change.

Only four IA reports explicitly described environmental assets in terms of benefits and constituents for an achievement of strategic goals (aid in the agriculture and forestry sectors in rural areas, exploration and production of hydrocarbons, prevention of spread of maize pest *Diabrotica*, and prohibition of driftnet fisheries). Six further reports stated limitations in methods and approaches for assessing potential benefits for human well-being, for example regarding integrated assessments of land use, land use change and biodiversity as well as benefits from a potential reallocation of resources from state aid. Table 2 gives a more detailed overview of the results from the documentary analysis.The indicator sets applied in the reports were largely sector-dependent, thereby addressing market regulation, production and consumer data as well as administrative handling. Data sources reached from member states to global institutions, stakeholder-based as well as statistical monitoring data and sector information. Environmental indicators in the impact sections often included GHG emissions, fuel consumption or emission rates, while in the evaluation and monitoring section hardly any indicator was suggested twice for reporting across all assessed IA reports. Overall, the indicators applied reportedly were to a large extent chosen in accordance with data availability. Levels of aggregation were compared for example at sector and subsector levels in the IA report on determining exposure of sectors to a significant risk of carbon leakage. A quest for new or aggregated indicators was articulated in other reports in regard to waste statistics, organic production impacts and biodiversity.

4.3. Synthesis

4.3.1. Does conceptual integration of the ecosystem services concept into IA make sense?

The European impact assessment process adheres to the paradigm of sustainability by its approach to balance benefits, values and trade-offs, and by drawing on foresight analysis and modelling tools to achieve accurate estimates about impacts (Bäcklund, 2009). At the same time, impact assessment is considered a learning process, carried out by interdisciplinary networks. The iterative adaptive learning during the decision-making process leads to an appropriate level of tension ("cognitive dissonance") that ultimately may lead to complex, adaptive behaviour (Bond and Morrison-Saunders, 2011). Adaptive learning networks have no legitimacy and must convince power networks by arguments, or by making use of positive feedback in the societal system. IA has led to processes where ministries cooperate at the highest level, and insiders indicate that for the first time the policy fragmentation that always has created barriers may have been overcome (Renda, 2006).

A core idea from complexity theories to dealing with dynamic systems, particularly in organisations which are of a multidimensional nature, is requisite variety (Nooteboom, 2007; Schwaninger, 1997). Requisite variety may be defined as the capability of systems to envisage the future changes in its environment and have a range of adaptive responses at its disposition (Nooteboom, 2007). The concept is loosely based on Ashby (1956) and has been linked with impact assessment procedures by Nooteboom (2007) and Rotmans (2006). Following their argument, the IA process provides support and structure in coordinating the integration of stakeholder perceptions and scientific data in formal decision making processes, with mandatory checks and balances. Thereby, impact assessment procedures can enhance the requisite variety in society in a changing world.

Table 2
Results from documentary survey of IA reports published in 2014.

IA reports 2014 (n = 57)	n	Example IA report	Example of indicators used for evaluation and monitoring
Environmental objectives	23	Calculation methods and reporting requirements relating to the quality of petrol and diesel fuels [COM(2014)617]	Fossil fuel greenhouse gas intensity; changes in EU refinery sector and supply of petroleum feedstocks; administrative burden on industry, including SMEs
Spatial dimension			
Explicit	9	Multiannual plan for stocks of cod, herring and sprat in the Baltic Sea [COM(2014)614]	Catch data (industrial, non-industrial); sampling of industrial landings; Stock abundance sampled by research vessels
Implicit	15	Policy framework for climate and energy in the period from 2020 to 2030 [COM(2014)15]	GHG emissions; GHG reductions; air pollution and related health impacts; GDP; GHG related to land use change
Environmental impacts			
No reference (0)	29	State aid for research and development and innovation [C(2014)3282]	Number of new researchers employed; new patents registered; productivity and gross value added
Not evaluated (1)	12	State aid to airports and airlines [C(2014)963]	Contribution to regional development by aggregate numbers of investment and employment
Weak evaluation (2)	5	Regulation on organic production and labelling of organic products [COM(2014)180]	Share of organic area; number of certified operators; value and volume of production by type of economic activity
Strong but no ESS (3)	10	Prevention of spread of *Diabrotica virgifera* [COM(2014)467]	Notification of outbreaks; crop rotation intensity; amount of insecticides used for control.
		Multiannual plan for stocks of cod, herring and sprat in the Baltic Sea [COM(2014)614]	Catch data (industrial, non-industrial); stock abundance sampled by research vessels
Framing of ESS (4)	1	Prohibition on driftnet fisheries [COM(2014)265]	Will be established with commission expert group in cooperation with the union fisheries control system and member states

The ESS concept is a tool for considering and managing societal obligations towards (a) the current generation of humans, (b) future generations of humans and (c) the natural environment (Abson et al., 2014). An operationalisation of ESS valuations accordingly holds a great promise as an instrument that can link policy makers and different scientific disciplines by bringing together transformative knowledge for collaboration towards sustainable development. Sustainability is recognised as an integrative and normative concept for decision making that is oriented towards system persistence and just allocation of resources (Abson et al., 2014; Pintér et al., 2012; Gibson, 2006).

Both assessment procedures (impact assessment and ESS) relate to the weak concept of sustainability. This implies the understanding that resources and benefits can be traded between different use options, regions and generations. The application of ESS as a link between environmental state descriptions (ESS and biodiversity) and human systems (human well-being) can bridge between scientific research and the organisation of decision support in policy appraisals (Helming et al., 2013; Müller and Burkhard, 2012). An obvious possibility would lie in the integration of the two concepts into adaptive management cycles at the operational level of policy formulation (Jordan and Russel, 2014; Dunbar et al., 2013).

By mapping ecosystems in juxtaposition to human systems and by translating environmental constituents in monetary economic and non-monetary social and biophysical terms, the ESS concept also links the three pillars of sustainability (Häyhä and Franzese, 2014; Braat and de Groot, 2012). The ESS concept can thus improve policies to achieve sustainable development by adding to the rather static idea of three separate dimensions (environmental, economic, and societal) currently assessed in the IA. By linking linear and non-linear relationships and illustrating cause and effect relationships the benefit will be an improved representation of impacts beyond the three dimensions of sustainability in the IA reports (Jordan and Russel, 2014; Maes et al., 2012; Hertin and Berkhout, 2010).

A framework has been proposed in the TEEB studies for policy decisions at international level, that sets human judgements and institutions determining the use of ESS at the centre of the ESS cascade (TEEB, 2009; Haines-Young and Potschin, 2009). Biophysical structures (including biodiversity) or processes translate into ecosystem functions, which are the base for ecosystem service delivery that translate into benefits and values in the socio-cultural context. In Fig. 2 this framework was adapted to the European Commission IA. Policy decision makers as well as regional and sector stakeholders are linked to the ESS cascade by feedback loops that illustrate how estimated and negotiated values can be coupled with framework programs as well as policy and management planning by the respective agents involved in an IA.

4.3.2. What could be potential benefits or misfits?

Many aspects of the ESS concept do not set it fundamentally apart from other integrated, comprehensive and stakeholder-led environmental assessments, such as environmental appraisal or sustainability assessment. Specific strengths are found in the following points (Cowell and Lennon, 2014; Baker et al., 2013; Dick et al., 2011):

- The positive way of framing ESS provision instead of the (often negative) impact on the environment leads to the description of benefits and suggests the accounting of environmental assets.
- Addressing questions of “use” and “perception” between stakeholders and decision makers and thereby also addressing conflicts between different sector arguments.
- Exploring the connectedness of social and ecological processes by making the different values (ecological and socio-economic) of ecosystems explicit for decision making while providing transparent evidence for policy formulation.

Another major concern relates to the danger that judgements regarding “good” management of ecosystems are based on implicit normative assumptions (Abson et al., 2014). However, the authors also argue that explicit regard for normative issues deepens the understanding of the role of ESS in relation to the broader societal goal of sustainability. Assessment of impacts, and thus also European Commission IA, requires a clear concept of sustainability as a societal goal, defined by criteria against which the assessment is conducted.

Political frameworks need information on human well-being in terms of health, food security, or risk avoidance. As long as available knowledge is not sufficiently linked to decisions, IA may raise awareness, but rarely seems to directly lead to sustainable strategic alternatives (Bebbington and Larrinaga, 2014; Nooteboom, 2007). Where a lack of data on monetary values exists, biodiversity and ESS can become a strategic goal for further policy development by addressing non-market goods and public goods. The application of intermediate tools used to integrate data, such as the often applied Driver-Pressure-State-Impact-Response approach, GIS-based tools or software-based indicator calculators, can change the form of research from problem-oriented analysis to a solution-oriented activity according to function.

4.3.3. What available evidence suggests that the idea of integration can be translated into practice?

Although much conceptual work has been conducted, there are few studies on the concrete application of the ESS framework for policies and decision making. Examples that explicitly test the concept for a particular impact assessment approach are the US National Environmental Policy Act to the US Forest Service (Presnall et al., 2014); or the embedding of the ESS approach in the UK National Ecosystem Assessment (Turnpenny et al., 2014).

The type and nature of indicator data needed by the policy sector is a common question in the debate of environmental research for decision making. On a national level, Turnpenny et al. (2014) found the inclusion of ecosystem services in existing assessments useful for requiring an analysis of environmental impacts, even where the final statement would be “no impact”. In the context of the UK NEA (UK National Ecosystem Assessment, 2014) being considered a driver for the inclusion of ESS, the limited uptake of indicators in principle provided by ESS research was however evident.

The application of indicator sets in the IA procedure is far less formalised than the structure and standardisation of the process itself. A large variety of single and aggregated indicators is used, and there is no indication for a usable definite set of indicators available that fits all policy appraisals. Aggregated and integrated indicators are called for in the impact assessment reports, particularly in regard to land use and land use change, as well as for an improved assessment of changes in biodiversity.

Previous studies found that in placing emphasis on ESS, the indicator level provides an entry point for transmission and integration (Paracchini et al., 2011; Müller and Burkhard, 2012). This becomes apparent in studies that show the overlaps in linking the different concepts of impact assessment and ESS, for example by structuring data, methods or impact areas along ESS categories (e.g. Bagstad et al., 2013 for decision support tools; De Groot et al., 2012 for market values per biome; Baker et al., 2013 and Helming et al., 2013 for policy impact areas; Burkhard et al., 2009 for land cover types). An improved illustration of these linkages can highlight potential synergies and gaps for innovative approaches towards the development of new indicators for safeguarding, management and risk assessment, but also monitoring or quality control. The

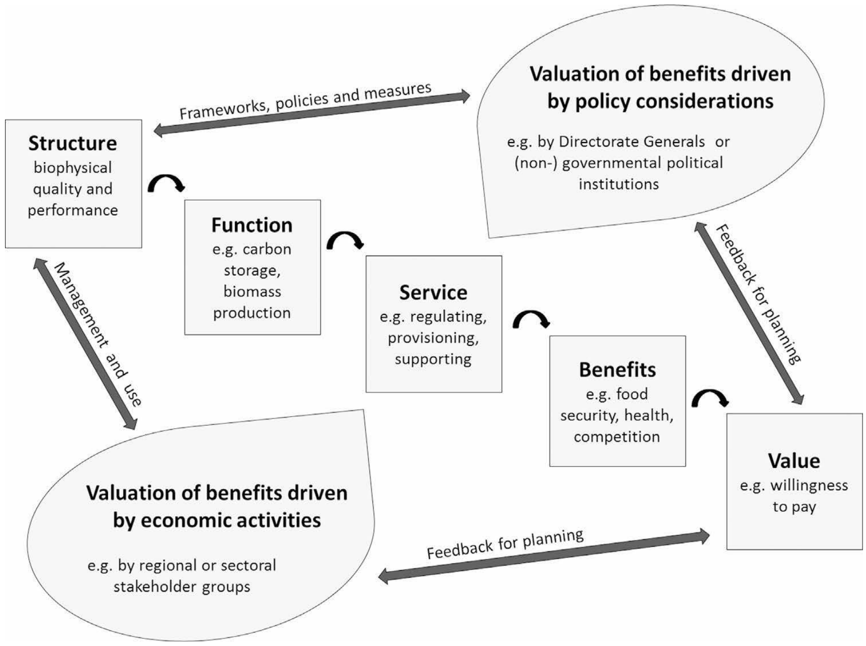

Fig. 2. Institutional constituents of European Commission impact assessment linked to the Economics of Ecosystems and Biodiversity (TEEB) overview diagram. Adapted from TEEB for Policy (2009) and Haines-Young and Potschin (2009).

Bellagio Sustainability Assessment and Measurement Principles (Bellagio STAMP) provide for example a practical framework for structuring indicator systems that measure progress towards sustainable development (Pintér et al., 2012; IISD, 1997). Current research in ESS focuses the definition of appropriate categorisation systems (Costanza, 2008) and indicators (such as CICES, see Haines-Young and Potschin, 2013). Further studies address the development of robust ESS quantification approaches and ESS data bases (Alkemade et al., 2014), spatial assessments of ESS supply and demand (Burkhard et al., 2012b) and the lack of transfer of scientific outcomes to policy, decision making and environmental management (Hauck et al., 2013).

4.3.4. What evidence available proves prospective "fit-for-purpose"?

The MEA and its associated outputs have resulted in nuanced conceptual models that allow explicit mapping of human-ecological systems based in environmental studies (Chapman, 2014). The monetisation of the quantitative relationships between ESS, human well-being components and environmental changes at first aimed at awareness raising, but soon it was followed by valuation studies for reasons of risk assessment, planning, assessment of trade-offs between different policy objectives or for the expression of relevance for degradation, intervention or restoration (Laurans et al., 2013; Braat and de Groot, 2012).

Although criteria and guiding questions are suggested for all three dimensions of sustainability, the IA reports do not follow a strict scoreboard type of exercise. Rather, the reports rely on indicators that are credible and may stand legal challenge in negotiations. The role of ESS in this context can fulfil several functions. Policy makers and stakeholders increasingly relate to the concept of ESS and would possibly agree on the relevancy of ESS as an integrated concept for environmental aspects as compared to an analysis of "all" impacts listed in the IA guidelines. The state of the environment (including biodiversity) and its functionality can be assessed based on respective indicators as well as on systemic interrelations of particular environmental properties and ESS.

From a technical point of view, ESS potentially provide additional data to be considered in assessing the cost and benefits of policy options. Measuring ESS can build on methods and comparable indicator sets as well as assessment schemes developed according to different research contexts. This leads to high flexibility for individually tailored solutions as well as widely accepted scientific knowledge in an international context, but also to difficulties in comparison between areas or research results (Hermann et al., 2011). Seppelt et al. (2012) provide a blueprint for documenting ecosystem service assessments for the benefit of researchers to enable comparison between studies, as well as for decision makers for structuring ES assessments or ES research studies, respectively. A comparable blueprint has been suggested by Crossman et al. (2013) for ESS mapping studies. This development is seen as a useful step towards improved monitoring methodologies and more standardised assessment approaches.

5. Discussion

ESS indicators are taken up in the European impact assessment reports to an overall low extent. This does not reflect recent discussion within the research community, where ESS are increasingly considered a viable tool for environmental integration in policy formulation. The question is whether the integration of the ESS concept is amenable to a possible time lag between its development in academia and use in policy practice or whether there are procedural or conceptual obstacles in regard to its applicability. This was considered an opportunity for discussing the integration of the ESS concept into European Commission IA for the means of improving the consideration of environmental benefits and values during framing and appraisal of new policies at European level. Here we come back to our initial research questions.

5.1. Is the EU ex ante *impact assessment procedure a suitable instrument to integrate the ESS concept?*

New policies can be viewed as innovations at the level of regulation. A baseline scenario for no-change will in general be favoured by all those adversely affected by the proposal for a new policy. In this context, the analysis of impacts in different pillars may lead to neglect or unconscious disregard of impacts, for example in assessments related to trade, transport or subsidy policies. The "virtuous circle" between benefits, beneficiaries and ESS is only connected when a broad range of ESS is recognised, and measures are taken to connect societal needs at broader spatial and temporal scales with local management "levers" (Everard et al., 2014).

For integration with the European Commission IA, we propose to explicate the "ecosystem service cascade" from Haines-Young and Potschin (2009) for the specific use at this level of decision making. The cascade model illustrates the entry points to the assessment procedure by emphasising the information flow to the different constituent institutions involved in an IA. Based on the rationale of improving the requisite variety for future decision making, the emphasis lies on the different entry points and possibilities for ESS application, rather than a limitation towards one single concept (Fischer, 2014).

An illustration of feedback links for the concrete case of European Commission IA would follow the proposition of Spangenberg et al. (2014) and Apitz (2013) to broaden the applicability of the "ecosystem service cascade" to different settings of policy formulation including the choosing between structurally different options at policy level. The ESS concept with its forward-looking affinity to scenario development and a positive planning-oriented approach matches the Commission's intention to look for viable solutions. Furthermore, it can provide for a meaningful simplification that allows for political negotiations between countries, sectors and regions.

The EU IA guidelines in turn would need to provide guidance for a more thorough implementation of ESS. Vlachopoulou et al. (2014) show at the example of the EU Water Framework Directive, how the objectives of the directive can be detailed and linked with ESS. This can be a first step to improve a *soft application*, given that the criteria are further conveyed to the description of the problem as well as the analysis of policy options and impacts. The *hard application* requires larger emphasis on evaluation studies that go beyond a comparison of costs for suggested measures within a policy framework to covering benefits and values of environmental services. A requirement for a more detailed description of the environmental state of the art in the baseline scenario can provide the basis for a later reflection of policy options. In many cases, however, as was also stated in the IA reports, this involves considerable advances in the availability of data and mapping.

There is a general consensus in the research literature that assessment criteria and indicators need to be put into the concrete context of the proposal. This finding is supported by the review of recently published IA reports, which shows little overlap in the indicator sets applied for assessment. The results of the literature review suggest the adaptation of ESS application to the respective step conducted in the IA (the successive sequence of framing of the problem, framing of options, analysis of impacts as well as monitoring and evaluation). For an improved operationalisation, previous studies have suggested to differentiate between explicit and implicit potential impacts on ecosystems, particularly in regard to spatial relevance (Helming et al., 2013). Further differentiation may be useful in regard to the level of abstraction conveyed in the IA conducted (policy framework or regulatory measures). This can give an indication whether the IA requires ecosystem-based framing at a conceptual level (*soft application*) or at an indicator level based on quantitative units and (monetary) values (*hard application*).

Advantages in practical implementation are seen particularly in three areas of application:

I. Up- and downscaling, including comparisons between different levels of aggregation in relation to time-related targets, sector-related impacts or spatial frames. This may improve particularly IA reports concerning monitoring, reporting or documentation issues.
II. Policy-relevant comparative analyses, including comparisons between different methodologies and aggregated indicators at different levels of scale.
III. Potential for innovation, including methodological approaches developed at the science–policy interface. This can lead for example to applicable aggregated indicators as well as suitable valuation and monitoring approaches for ecosystem-based resources in terms of benefits.

5.2. Can the ESS concept theoretically comply with the requirements and demands of an actual European impact assessment process in order to be operational?

Ecosystem service research is an example for transdisciplinary research that tries to move beyond the employment of several aspect visions to develop synthesised or novel perspectives (Buanes and Jentoft, 2009). Natural elements are analysed with a focus on their mutual impact and interdependency between each other and with the society, thereby drawing attention towards interactions and processes that occur at the system level. This resulted in its perception of an altogether too complex framework for decision making. Weaknesses relate to the complexity of the approach, and to the general problem of environmental issues not being central to human planning and decision making. On the other hand, research has increased almost exponentially over the last years, with new concepts coming up at great pace. The application of the ESS concept has moved forward substantially in taking up a solution-oriented focus on environmental management problems. It can thus be considered as an intermediate instrument that links primary research data with impact issues relevant for decision making.

Strength of the ESS approach lies in the combination of ecological and socio-economic data, tools and methods. Based on the considerable work in the mapping of ESS in recent years, the integration of the concept can effectuate new or improved integrated environmental indicators (Maes et al., 2012; Seppelt et al., 2012). The translation of ecosystem services into value systems involves monetary and non-monetary approaches as well as the communication of aggregated ESS indexes. Therefore, appropriate communication and mediation tools need to be created and applied, in order to achieve an integrated and even stakeholder-based approach to sustainable resources planning that involves ESS quantification, mapping and evaluation (Cowell and Lennon, 2014).

The Millennium Ecosystem Assessment and the TEEB studies have brought biodiversity into political considerations, resulting e.g. in the European Biodiversity Strategy. Moreover, natural capital and conservation of natural resources such as water and soil have moved up the political agenda. The realisation of agriculture as one important sector not only for food security but also for landscape management demands integrated assessments that are based on consistent frameworks coupling process models with ESS. Ecosystem services as well as natural capital and biodiversity issues will need to be factored in for adequately addressing land use-based issues at a strategic level.

The ESS concept complies with the requirements and demands of an actual European IA process by relating environmental aspects to benefits relevant for societal impacts, and to value indicators that can improve the economic section of the impact assessment report. By linking environmental concerns to human benefits and economic values, ESS indicators encompass an application in the environmental dimension only and may also provide for new indicator sets. Open questions remain in regard to the high levels of abstraction in IA, and the applicability of the ESS concept in strictly governance-oriented regulations (market regulation, competition, merger control).

6. Conclusions

The aim of this paper was to analyse conceptual, technical, ethical and pragmatic aspects of a potential integration of the ESS concept in EC IA in order to reflect whether European policy IA is a suitable instrument for integration, and whether the ESS concept can comply with the requirements of an IA for operationalisation.

It was found that indicator sets applied in the impact assessment reports follow a much less formalised structure than the reports or the procedure. An integration of the ecosystem services concept would enhance the requisite variety of indicators used, and thus contribute to the overall goal for sustainable development. Potentials for improving IA lie particularly in the up- and downscaling of benefits and values, policy relevant comparative studies and the prospective possibilities for innovation in indicator development. Based on this rationale of improving requisite variety for future decision making, the emphasis lies on a further development of the ESS concept along two pathways of operationalisation: the translation of the concept for a comprehensive approach at a higher level of abstraction (*soft application*), and the application of the concept for providing aggregated, quantitative and unit-based information at different steps of an IA (*hard application*). Entry points exist at various interfaces of science–policy interaction. Furthermore, the translation from services to benefits, benefits to values as well as values to regulatory measures for policy planning responds to and feeds back to the state and performance of the biophysical environment via governance measures. The cascade model helps to illustrate entry points to the assessment procedure by emphasising the information flow to the different constituent institutions involved in the assessment.

The applicability of ESS was found to depend largely on the context and framing of the IA report, rather than on a limitation of approaches in ESS towards one single concept. This suggests the consideration of the level of abstraction addressed by the new regulation as well as a targeted application of suitable intermediate tools for data integration for different means at each step of an IA.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2015.07.013

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3

Discussion

3.1 Objectives and Design of the Framework THIS

The overall objective of this study is to provide knowledge of the interlinkage between agricultural practice, research and policy by applying a Triple Helix System of Innovation for Sustainability (THIS) using selected case studies in the agricultural sector.

The analysis builds upon the Triple Helix System of Innovation described by Ranga and Etzkowitz (2013). Originally the framework was developed to describe and analyse university-industry-government (triple helix) interactions by highlighting the innovation process in the Innovation System. Thus, it breaks down a concrete targeted development-orientied activity into a defined set of components, relationships and functions. The framework has proved useful in the context of development studies and foreign aid, where new ways of interaction based on radical changes are sought (Shinn 2002).

The framework was adapted and specified to cases of sustainability-oriented innovations in agriculture by differentiating market-driven functions and sustainability-oriented functions. By integrating sustainability, issues of governance (also of steering and control) move from the more simple navigation between technology and market requirements to an extra engagement required to accomodate expectations in regard to sustainability. Thereby, each spiral introduces its normative elements into the process. Negotiation of goals thus becomes an essential activity in achieving a comprehensive innovation process for sustainability in agro-ecosystems that is coherent across spirals.

The Triple Helix System of Innovation for Sustainability (THIS) was effectively divided into three levels of relationship interaction, based on an identified main component in case studies. Each level represents one aspect of institutional relationships relevant to the negotiation of functions, including 1) technological aspects, 2) organisational aspects, and 3) governance aspects (**Chapter 1, Fig. 1**).

The series of independent studies presented in **Chapter 2** looks into distinct questions at each level of relationship interaction. An overview of the results on the linkage between market-driven processes and sustainability-oriented activities is presented in **Table 2**. **Chapter 3** discusses how the Triple Helix System of Innovation for Sustainability (THIS) is structured by the technological, organisational and governance levels of institutional interaction. In the following, all levels are taken into account to specifically elaborate on the relevance of negotiation processes in the context of *ex ante* impact assessment approaches that aim to improve a prognostic understanding of sustainability-oriented innovations in agriculture. Final conclusions are given in **Chapter 4**.

Table 2 Summary of Case Study Results.

Research foci (see Chapter 1)	**Main findings from the case studies**	**Ch**	**Case Study**
Early planning stages of innovation development	The technological, organisational and governance level need to be considered *ex ante*. Market-driven and sustainability-oriented activities can be negotiated along a framework of short-term innovation management goals and long-term sustainable development targets.	2.1	EVI (1) ASTAF Pro (2) EiCare (3) HayHeat (4)
Prototyping and field testing	Transdisciplinary research projects can prevent market failure, but the elimination of organisational and governance issues from technological innovation development risks systemic failure.	2.2	EVI (1)
Innovation development targets	An actor-based definition of sustainability-oriented innovations is presented that requires an innovation to 1) improve local added-value, 2) contribute to closed material cycles, and 3) improve the capacity of actors to develop.	2.3	EiCare (3) HayHeat (4)
Managerial functions in research networks	The set-up of an innovation supporting transdisciplinary research network requires a “re-invention of the wheel” process. Managerial functions in research follow an inverted time schedule as compared to partners in business practice.	2.4	SENSOR IP (5)
Organisational structure of research networks	Durable structures for innovation support from research networks require long-term incentives by public funding organisations to maintain the values of the joint knowledge base.	2.5	LIAISE NoE (6)
Integration of environmental aspects into policies	The ecosystem services framework offers a concept for operationalising sustainability in policies. Soft application of the concept (comprehensive approach) can avoid systemic failures in sustainability planning, while hard application (aggregated, quantitative and unit-based information) can avoid knowledge-based decision-making failures.	2.6	EU IA (7)

Ch: Chapter

3.2 Technological Level of Interactions in Sustainability-oriented Innovation Processes

North-eastern Germany is one example of a European region characterised predominantly by agricultural land use. It has a diverse research infrastructure in the agriculture, food and environmental sectors embedded in a dense network of innovation brokers, technology transfer offices and downstream enterprises towards the capital city of Berlin. A large fraction of farmers is highly qualified (approximately one third of the farmers have a university degree), is aware of changes in markets and policy, and has access to public funds (BonnEval 2012). On the other hand, privatisation of agricultural extension services, fragmentation of consultative institutions and a re-orientation in the research domain have led to an undervalued potential for innovation in the region (König et al. 2011; Dimter et al. 2008). Gaps in the innovation system are categorised as procedural and administrative rather than technical or topical. Otherwise, innovation needs were seen equally in very specific agricultural sections (e.g. mechanical sorting of cucumbers) and in comprehensive challenges (e.g. conservation of land as a resource) (Beblek et al. 2014). The broad range of innovation needs indicates weak frame conditions for innovation development, caused either by insufficient creative expression or a void in support from the side of administration and policy (König et al. 2010). Farmers articulate an unmet need for a constant and reliable knowledge transfer from agricultural research organisations that could be met with bottom-up approaches to problem-solving (e.g. see the previously-mentioned European Innovation Partnerships (EIP)).

In **Section I**, the analysis focuses an innovation process at the technological level of relationship interaction. Four selected case studies represent this level with their key purpose: technological development for sustainability. These case studies are characterised as newly-emerged ideas and inventions that are expected to contribute to a transition to sustainable agro-ecosystems, and achieve market relevance. All four selected case-study innovations are categorised as system innovations that require a broad change process beyond the implementation of new technology (Elzen et al. 2004; Geels 2005). System innovations generally include simultaneous adaptations in farm management, adaptations in the production system or the business model as well as new combinations of resources. The case studies were deliberately selected based on the complex quality of the innovations. All four were perceived to require site-specific adaptation in implementation, cross-sector actor involvement during the development process or beyond, and local expertise as well as scientific input on detailed questions of development. Furthermore, the actors involved in the innovation process articulated a need for external support to achieve market relevance next to targeted sustainability goals.

Case Study 1) **EVI**: a biological control agent for soil-borne pathogen regulation (2009–2014);

Case Study 2) **ASTAF Pro**: a double recirculation system for aquaponic production of fish and tomatoes (2009–2014);

Case Study 3) **EiCare**: a marketing strategy for re-introduction of dual-purpose poultry production (2014–2019);

Case Study 4) **HayHeat**: a small-scale thermal energy production plant for using surplus biomass in marginal wet grassland (2014–2019).

The triple helix set-up includes actors from agricultural practice, research and policy, their interaction ensured by a coordinated series of focus group workshops for mutual information flow (König et al. 2016; König et al. 2010). The three spirals are found to follow an unbalanced structure similar in all four case studies, with a strong representation of research and agricultural practice, but an underrepresentation of actors from policy – and thus the normative elements of sustainability contained in this spiral. While an integration of representatives from the federal-state level appears obvious in regard to the regional scope of the case studies, the expression of ethical, legal, financial and institutional issues is largely taken up by farmer associations and marketing organisations. The group of actors from agricultural practice includes suppliers, producers and wholesalers. The research spiral is represented by an interdisciplinary set of researchers, ideally spanning different research organisations and disciplines.

In moving along the innovation process in the analysis of all case studies, it is observed that an uneven composition of the triple helix at the technological level is characteristic. A strong representation of research and agricultural practice is required where questions of technological feasibility and compatibility with market requirements stand in the foreground. Participating actors representing different positions across the value chain are driven by their interest to gain early insight into new developments, while seeking to protect established approaches and technologies as gate-keepers. The interaction within focus groups provides for detailed knowledge on technological fit as perceived from the different angles of the value chain, and a detailed insight into opportunities and risks. Questions of sustainability, and thus of political fit, play a limited role at this stage, although all four case study innovations are promoted as sustainability-oriented by the involved actors. Partly, actors assume environmental benefits as a driver of development of the innovative approach in the first place. Actors from agricultural practice clearly prioritise activities needed to achieve diffusion and utilisation of the innovation by adapting to production processes and marketing channels. Actors from policy take a similar stance, thereby offering funding and support for match-making, networking, market analysis and protection of intellectual property. Whereas in regard to sustainability, policy actors regard themselves as guides with an "*advisory role, in which the consequences of decisions taken by land* *users and stakeholders are highlighted across all levels of sustainability in an objectified way in order to qualify decisions*" (pers. comm. of a senior decision maker in Brandenburg, in Diehl & Baumeister 2017, p. 196). This rather passive engagement builds on knowledge input from research but avoids a position of steering and governance. It also leaves actors from research with a dual role: providing knowledge for innovations in agricultural practice, and collecting data for estimations of innovation impact while communicating the results to policy actors.

Several issues arise from the unbalanced setting that extends beyond the realm of technological development to other levels of relationship interaction. One issue concerns the organisation of research support in a durable and meaningful way; another issue concerns the provision of criteria for guidance from policy. Analysis at the technological level, however, was observed to require structured information on the innovation system for early management planning, a roadmap for integrating sustainability requirements into project planning, and a clear definition of target goals for sustainability-oriented innovations that can be used for further assessment and monitoring, particularly by representatives from policy. The results from Section I give some insight into these issues.

The application of a systemic foresight process is used in **Chapter 2.1** to apply a hierarchical system to a time schedule for future innovation development. Participatory innovation assessment is used for the integration of market-oriented goals, while expert-based impact assessment is used for the integration of sustainability goals. The triple helix set-up in THIS provides for the articulation of options and requirements by representatives from agricultural practice, research and policy. A strong engagement of actors in regard to innovation management, but a weak engagement of actors towards sustainability goals is observed to lead to a strong recognition of market failures, but little recognition of systemic failures (where policy comes in). Thus, the achievement of positive externalities in regard to sustainability impacts becomes underrepresented in management and planning, while, for example, steps towards achieving a competitive market price dominate the process. The results highlight the need for an organisational structure that ensures an early integration of policy to address this shortcoming. The observation supports similar findings from an application of triple helix approaches to support small and medium enterprises (SMEs) in sectors other than agriculture (Ranga et al. 2008), particularly at a local level (Danson & Todeva 2016). In regard to SME support, local and regional authorities through their involvement shorten the distance between decision-making and implementation by facilitating, for example, stakeholder consultation. This in turn has an effect on value creation and value capture at the local level. In agriculture, relevant case studies show the importance of policy involvement to compensate for insufficient formalisation of relationships between actors in agricultural practice, for example by facilitating capacities for collaboration and financial or in-kind investment. Furthermore, the conceptual nature of the inventions covered by the case studies requires adaptation to specific localities. This results in less obvious potential for lock-in, as opposed to established and specialised value chains.

In negotiating the market perspective, it is found that sustainability-oriented innovations at the technological level are challenged by powerful lock-in effects of existing value chains in agriculture. Specialisation has reached a stage, where alternative production pathways become increasingly difficult to implement within the existing infrastructure. This is partly caused by specialisation in sub-sectors that have developed in isolated fashion. For example, green house production of vegetables and aquaponic production of fish (Case Study 1: ASTAF Pro) have developed into completely separate production and marketing chains. For a further establishment of a combined system, these separate supply chains have to be addressed in parallel, and merged to a certain extent to achieve market entry. Other reasons are found in the isolated development of production steps within the supply chain, as shown in the example of applying a biological control agent to strawberry production (Case Study 2: EVI). The supply of plant material for strawberry production is isolated from the strawberry producers, with separate and partly nontransparent material flows, and little communication between plant material producers and strawberry farmers. In effect, the lack of knowledge about technical mechanisms in adjacent sub-sectors or supply chains can lead to ecological risks (e.g. import of soil-borne pests with plant material), but also to insecurities in terms of approval from local authorities (e.g. environmental compatibility and application safety of the biological control agent) or in terms of policy direction (e.g. allocation of responsibility in order to reduce the spread of pathogens).

Thus, the separation of sub-sectors and supply chains leads to additional expenses during the innovation process, particularly in developing alternative value chains both on the supply side as well as in distribution and marketing. Activities for building new communication channels and alternative cooperation frameworks will entail inefficiencies as compared to standard processes in specialised agricultural production processes, and thus negatively impact the revenue situation of each partner involved. Reflexive (cyclic) and iterative management is required to move the innovation process forward in spite of potential risks and losses involved in such activities, with additional experts coming in from policy. The implementation of traditional poultry breeds for small-scale production of eggs and meat (Case Study 3: EiCare) highlights the relevance of infrastructural resources and entrepreneurial capabilities: necessary permits for henhouses are standardised to large scale production, as are the required numbers of animals for a slaughterhouse or veterinarian fees. Each step requires a specific local solution based on communication and cooperation in regional and sectoral networks (Diehl et al. 2015). The significant logistical effort that is required of the individual and, – due to local idiosyncrasies – not transferable solution, makes definition of new value chains very case-specific for innovation case studies in agriculture. In comparison to product innovations, where such processes can be standardised through piloting and transfer, such individualised processes not only amplify the initial development costs, but also the production costs per unit during market establishment and the time needed to achieve break-even. The extra expenses need to be taken into account in early assessment of an innovation.

In small and medium enterprises (SME), new resource-combinations for sustainability-oriented innovations may require entirely new business models that source from collaboration in cross-sectoral networks (Halme & Korpela 2013). Previous studies building on resource-based theories suggest that competitive advantage in changing market environments is determined by employing dynamic and entrepreneurial capabilities rather than by employing valuable, rare or inimitable resources (Newbert 2007; Alvarez & Busenitz 2001; Porter 1985). Such findings suggest that extra expenses for creating new and individual value chains are worthwhile in the long term. The development of new infrastructure for alternative production and marketing channels and the definition of new business models, however, involve a strong incentive on the side of the producers to engage in activities that help to overcome such initial market inefficiencies. In the case studies, the driving actors all have a strong regional focus to participate in providing for sustainable agro-ecosystems.

In negotiating sustainable development issues, it is observed that all selected case studies may lead to more sustainable agro-ecosystems by providing benefits that are only emotionally accessible to producers or consumers. In the case of ASTAF Pro (Case Study 1), the benefits lie in water consumption efficiency, avoidance of pesticides and wastewater, as well as support of local production in rural and urban areas. In the case of EVI (Case Study 2), the avoidance of potentially harmful chemical treatment in pest management stands at out. In the case of re-introducing traditional poultry breeds for dual-purpose production (Case Study 3: EiCare) the benefits are mainly linked to ethical issues, such as avoidance of male chicken culling and conservation of traditional breeds. In the case of thermal energy production from surplus biomass (Case Study 4: HayHeat) the benefits lie in the conservation of marginal wetland habitats and the energetic use of surplus biomass. Other beneficial aspects of all four case studies are found in the support of a sustained population structure, upheld e.g. by local value creation through small-scale agriculture, local tourism and a support of local production.

The usefulness of integrating sustainability issues into project planning are described in EVI (Case Study 2) in **Chapter 2.2** as one example, where the benefits are readily visible and can be broadly analysed. The triple helix interaction is applied in the form of focus-group workshops to design prototyping and field testing under real production conditions for the particular case of applying a biological control agent (BCA) in pest regulation (*Verticillium*). The BCA is based on a patented mixture of non-pathogenic strains (Lentzsch et al. 2015) as an alternative to chemical treatment which is forbidden under current EU regulations. The interaction, by means of a structured questionnaire, with actors from research, agricultural practice and policy has a considerable qualifying effect on the technological level of the innovation process.

By conducting the field testing at the actual location of the production site, the effect of the BCA can be observed in direct comparison to general production in the field. The application shows positive results in achieving the transferability of the concept to practice. The systematic adjustment of the BCA technology to production processes largely relies on upscaling the biologic preparation by commercial fermentation based on available laboratory technology. The result is a production-conforming BCA technology design that can be integrated into local planting schemes and different field sizes or machinery. Further development is however impeded by unforeseen microbial-ecological effects that restrict the benefit of the BCA (particularly an increased prevalence of *Phytophtora*). Such an outcome would lead to a situation where agricultural practitioners reject the invention so that research must recommence if the method is to be successful. By building on the previously established joint knowledge base, however, three possible solutions develop from the initial monocausal situation:

1. Use of certified high quality plant material to avoid microbialogic interaction in field;
2. Detection of *Verticillium* before planting and, where required, parcel exchange;
3. Chemical treatment for pest regulation in plants to eliminate *Phytophtora*.

Each solution entails an assessment of feasibility and the definition of further development steps. Certified plant material, for example, requires regulation and monitoring by public authorities, while early detection of pathogens in soils requires more research and development in order to provide affordable analytic methods. Although *Verticillium* affects a large number of plant species, the problem has not gained sufficient economic relevance to be considered by private research (pers. comm. KWS SAAT SE, Einbeck, 7. May 2013). Public research on the other hand lacks appropriate structures to take on the spread of *Verticillium* as a research topic over a sufficiently long period of time. The validation of a positive repercussion of concurrent *Phytophtora* treatment on BCA effectiveness requires further experimental research and testing of the BCA in combination with available chemical or biological control of *Phytophtora*. This, however, implies research projects with temporal flexibility, e.g. the possibility to prolong projects under the same call based on previous results. The positive repercussion of *Phytophtora* treatment on the BCA effect could then be validated, as was done in this case within an independent project that followed up on the results presented in **Chapter 2.2** (Lentzsch & Embach 2015).

Next to questions of feasibility, which can be assessed in terms of technological and market requirements by the representatives of the research and agricultural practice spirals, the pre-assessment of possible options needs to take into account sustainability issues that particularly require input from the policy spiral. One main question to be answered is: Which of the three options, or elements, are socially favoured?

The representatives of both the spiral of research and the spiral of agricultural practice will select an appropriate choice in accordance with the normative elements within their own sphere of activities, and refer to issues of organisation and management. In agricultural practice, the selection decision is based on cost and labour effectiveness in farm and plot management. In research, the selection decision involves a strategic provision for research priorities and publication-oriented output. The choices are influenced by intensified global competition which further reinforces standardisation in innovation and research. Rieu (2014) describes this development as a mutation of the conception, organisation and role of all knowledge activities in advanced industrial societies since the 1980s. In seeking to compete, institutions follow similar priorities and objectives and are thus under pressure to standardise processes for reducing costs. On the one hand, standardisation can foster cooperation between institutions within, as well as across, domains. But on the other hand, a lack of diversity in approaches negatively influences the search for solutions in regard to environmental constraints and systemic crisis.

The steering of intended and unintended, short- and long-term, direct and indirect impacts is strongly influenced by the sphere of policy and governance. This would be exemplified with a strong representation of the policy spiral at the technological level having the potential to positively influence the assessment and planning of the use of non-pathogenic *Verticillium* strains as an alternative measure for regulation. This can be achieved by addressing frame conditions at higher systemic levels of the system in the sense of translation of sustainability into a cyclic, reflexive form of organisation and governance. Certified plant material, for example, entails active regulatory intervention in the market by standardisation of production and supply, with an impact on suppliers in terms of guarantees and insurance. Furthermore, policy input at this level facilitates communication with additional actors required in the assessment, such as actors from plant propagation, or development of analytical instruments for detection. Chemical treatment of plants, for example, questions the positive environmental benefit of using biological control agents, while parcel exchange may involve further assessment (e.g. in regard to availability of land) or accompanying measures (e.g. investment support for farmers).

Where the sustainability aspects of an innovation cannot be experienced by market participants directly via economic benefits, activities to further develop the innovation have to be legitimised by political frame conditions. Furthermore, where the policy frame conditions do not support sustainability-oriented development, the invention will fail as an innovation on the market. This leaves us with the question, how can sustainable development be framed at the technological level, particularly for further engagement with policy-makers?

Upon having established a joint knowledge base that describes the situation in which each case-study innovation is embedded (König et al. 2016), the desired and undesired impacts are observed to be diverse across case studies and actor groups. The reason is that each case study builds upon a different set of underlying assumptions related to the respective sustainability goals and concepts applied. As mentioned before, EVI (Case Study 1) and EiCare (Case Study 3) relate to ethical issues of sustainable production and consumption whereas ASTAF Pro (Case Study 2) and HayHeat (Case Study 4) relate to issues of circular material flows and conservation of natural resources. At the global level, sustainability is calculable in aggregate and thus predictable in a tangible way, reflected partly by research data. At the local level, sustainability concepts have to translate into substantive foci that are meaningful to producers and effective within a specific agro-ecosystem.

In addressing these substantive foci in agricultural practice, each case study has its own particular aim and history. As observed, these include the origin of the invention (research or practice), the institutional sphere in which it is developed (region or sector) and the development target articulated by the innovators. In each case study this results in a specific imbalance regarding a triple helix interaction. By applying THIS it is possible to detect the relevant gaps, and thereupon actively manage the innovation process toward sustainability goals articulated at the global level, such as according to the UN Sustainability Development Goals (SDG) (UN 2015) (**Fig. 2**).

The substantive foci in the case studies comprise avoidance of chemical pollution (translated from SDG target 12) (Case Study 1: EVI), technically improving closed material cycles (translated from SDG target 12) (Case Study 2: ASTAF Pro), dual-purpose production (eggs and meat) through use of traditional breeds (translated from SDG target 2) (Case Study 3: EiCare) and the conservation of biodiversity and reuse of waste biomass material (translated from SDG target 12 and 15) (Case Study 4: HayHeat). The integration of these substantive foci for sustainability remains the task of additional experts outside of agricultural practice, ideally representing the policy spiral.

Where the spiral remains unbalanced, sustainability goals will be inadequately represented in the negotiation process. Actual operating data based on accounting and management data as well as ecological impact data are available to a limited

SDG 2	Zero Hunger (selected targets)
	• Sustainable food production systems and resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, and that progressively improve land and soil quality. • Genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species.
SDG 8	**Decent work and economic growth (selected targets)**
	• Achieve higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on high-value added. • Encourage the formalisation and growth of micro-, small- and medium-sized enterprises.
SDG 12	**Responsible Production and Consumption (selected targets)**
	• Sustainable management and efficient use of natural resources. • Environmentally sound management of chemicals and wastes, and reduction of their release to air, water and soil. • Reduction of waste generation through prevention, reduction, recycling and reuse.
SDG 15	**Life on Land (selected targets)**
	• Reduce the degradation of natural habitats and halt the loss of biodiversity.

Fig. 2 Selected targets from Sustainable Development Goals (SDG) (UN 2015).

extent in an innovation process at farm level. The data limitations partly lie in the nature of the innovation process itself: processes and outcomes are new and thus activities are exploratory, while the outcome may not necessarily be matched with previous outcomes. General time constraints and unfamiliarity with the object of exploration on the side of the farmers add to the lack of data.

In the absence of a benchmark, e.g. regarding breed-specific characteristics, performance of small flocks or ecosystem requirements in the case of EiCare (Case Study 3), an up-translation from existing data (**Fig. 3**) is not achievable. Thus, sustainability benefits cannot be quantified. In order to pin down the sustainability values at the technological level of agricultural practice, interviews with 28 actors were conducted subsequently in two case studies (Case Study 3: EiCare and Case Study 4: HayHeat).

Questioned about their individual perceptions of sustainability values in regard to the respective innovation, it was possible to select and cluster the following criteria for sustainability via content analysis (**Chapter 2.3**):

a. achieve local beneficiary effects through local added-value and provision of ecosystem services (related to SDG 2 and 12),
b. contribute to sustainability in production and marketing through closed material cycles (related to SDG 12), and
c. support a capacity for sustainable growth through horizontal and vertical development (related to SDG 8 and 15).

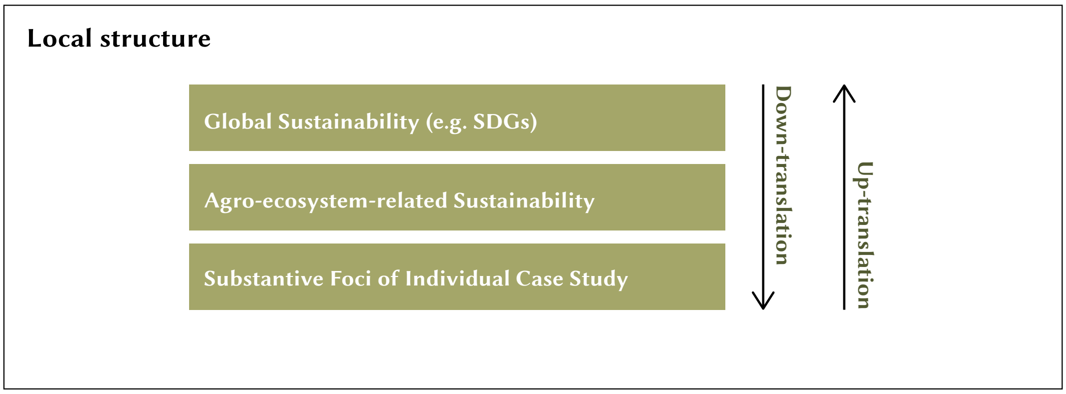

Fig. 3 Up- and down-translation between Substantive Focus (local level) and the Sustainable Development Goals (SDG) (global level).

The combined effect is perceived as an additional asset in addition to local, organic or conventional smallholder production by the actors involved. It describes an agro-ecological factor of local value creation that can be applied to establish the underlying conditions of a sustainability-oriented innovation at the level of the agro-ecosystem.

This actor-based definition of a sustainability-oriented innovation deviates from previous approaches in two ways. Firstly, the definition is entirely based on a local, actors' understanding of sustainability. It can be applied to assess a prototypical innovation within the regional focus or sectoral setting. Secondly, it is based on an *ex ante* perspective where the actors communicate what is to them the desired positive impact of the sustainability-oriented innovation. This would otherwise be done in reference to a global understanding of sustainability (e.g. Sustainable Development Goals by the UN).

The up- and down-translation requires the determination of suitable criteria by the representatives of all three spirals. While the positive contribution of the innovative production system to the agro-ecosystem or the SDGs is not calculable in EiCare (Case Study 3), one criterion is the potential reproducibility of the dual-purpose production system within the agro-ecosystem (e.g. in Brandenburg as one agricultural region with a distinct climate and soil). In absence of economic data, it is possible to estimate and compare the reproducibility based on the size of flocks and the requirement of area and feed to conventional production. The potential number of farms up to the given limit of one factor (feed, area) would thus describe the scope for sustainable growth and upscale of the sustainability-oriented innovation. It is thus possible to calculate a replacement effect of the innovation against existing production systems. The implementation of the ASTAF Pro system (Case Study 2), for example, is currently being used to produce the quantity of herbs required by one supermarket chain to satisfy the market demand for organic basil in the capital region of Berlin (at the expense of other production systems) (pers. comm. ECF Farmssystems GmbH, Berlin, 5. May 2017).

However, this estimation does not describe the positive contribution of the production system in terms of services, such as the value of conserving traditional breeds, the value of dual-purpose production in small-scale farm structures, or the value of not culling male chickens. In the absence of a discrete calculation of these value contributions, the particular societal contribution required to establish the innovation (e.g. in the form of subsidies) cannot be described *per se*. The main barrier in the innovation process is therefore the communication of a business case for a product that is in itself equal in type and quality to comparable offerings from other production systems, but integrates additional services that are neither tangible nor calculable. Where compensatory properties cannot be communicated, this can lead to a premature termination of the innovation process. While EiCare (Case Study 3) and HayHeat (Case Study 4) are still ongoing, EVI (Case Study 1) and ASTAF Pro (Case Study 2) were concluded in 2011. In both cases, the positive contribution of a change in the production system is not calculable, as described above. In the case of EVI, this concerns, for example, the preventative application of the biological control agent in EVI as an alternative to chemical treatment in pest regulation. In the case of ASTAF Pro, this concerns the re-cycling of water and nutrients in combined fish and vegetable greenhouse production.

Other approaches for sustainability calculations in local structures (**Fig. 3**) largely rely on the ecosystem, whereby the sustainability value will be balanced and accounted for. The Ecosystem Services (ESS) concept supports a strategic assessment of (ecological and societal) services linked to components of human well-being (MEA 2005; Leemans & de Groot 2003). In contrast to THIS (see above), the ESS concept cannot be translated down to the substantive foci. "*Things like global climate regulation, biodiversity and freshwater services tend to be shared collectively by social groups; individuals do not own them outright*" (Wilson & Howarth 2002). Instead, innovations are considered an external driver of change, whereas the relative change can be calculated at the level of the agro-ecosystem.

Nevertheless, the visionary and ideological goal that was formulated for the global level of sustainability needs to be translated down to the factual, material level (substantive foci) of the case studies (**Fig. 4**). The definition of such an "innovation service" requires a regional and time-related harmonisation of standards to provide a benchmark for the innovation process. If THIS is administered, criteria can be defined and calculated for the substantive foci by reflecting on the contribution of the sustainability-oriented innovation to the local structure from the perspectives of agricultural practice, research and policy. While the SDGs or the ESS can be used as auxiliary concepts, the resulting criteria will describe the contribution of the sustainability-oriented innovation within the local structure of the case study. Thus, the contribution to the agro-ecosystem can be described in the form of a value-adding factor for a local eco-system. The prerequisite for this step is the input from policy. The contribution to the agro-ecosystem can then be further substantiated with calculable indicators (e.g. amount of produce, number of production units, value added).

Contribution to sustainability within the local structure

Substantive Foci of EiCare	Ecosystem Service	Contribution to the Agro-ecosystem
Dual-purpose production (eggs and meat) through • use of traditional breeds • use of organic feed • area extensive production • small flocks • No culling of male chicken	Provisioning Services • Food • Genetic Resources	Organic production of organic meat and eggs at the expense of other production systems
	Cultural Services • Cultural heritage • Sense of place	Provision of meat and eggs within the calculated limits of the performance of the dual-purpose breeds and the availability of resources (area, feed)
		Location sensitive agriculture under consideration of limited production capacities and local settings (population, infrastructure)

Fig. 4 Estimation of Sustainability Impacts on the Agro-ecosystem by using Ecosystem Services (ESS), at the Example of EiCare (Case Study 3).

The main results from applying THIS at the technological level of an innovation process are shown in **Table 3** (second column) according to the criteria of THIS. It can be observed that an assessment of the innovation and reflection against sustainability targets for an agro-ecosystem and global impact is required as an ongoing process in innovation management that requires the integration of representatives from policy as a precondition. The translation of sustainability goals to the local structure therefore depends on the maintenance of relationship-interaction, by policy, in each phase of development of the innovation process. The innovation process must therefore be guided through a continuous and cyclic organisational structure led by policy.

3.3 Organisational Level of Interactions in Sustainability-oriented Innovation Processes

Translation processes in the form of knowledge and technology transfer between the domains of research, agricultural practice and policy are activities to be expected in an innovation process. The application of THIS at an organisational level focuses on the iteration and reflection required to link the representatives of the research, policy and agricultural practice spirals, as well as overall sustainability goals and the substantive foci of the individual case study. While the technological level shows underrepresentation of the policy spiral, and is largely defined by agricultural practice, it is found that the organisational level of relationship-interaction for sustainability-oriented innovation processes is mainly defined by researchers. Agricultural practice at both levels is focused on the implementation of substantive foci under consideration of market requirements,

In this context, project-based research has become increasingly relevant in knowledge and technology transfer, often in the form of collaborative projects that include actors from within and outside of science. When applying aggregated knowledge from foresight excercises to the design of sustainable agro-ecosystems, interdisciplinary cross-scale analysis is required to negotiate solutions that link between drivers of conflict and fields of opportunity (Giller et al. 2008). Temporary project consortia allow scientists and research organisations to keep their identity as scientific institutions anchored within the scientific system while engaging with users and practitioners (Braun 2003; OECD 2013). From the position of the project, scientists can offer data, methods and tools to users in an application oriented environment. In the case studies presented here, researchers involved in transdisciplinary, project-based research take on a main role at the organisational level. Their role involves mediation between the three spirals by providing expertise-led prioritisation, organisation and management of the innovation process.

Ideally, the activities take place in a sheltered niche, where ideas can be adapted, tested and evaluated against the immediate requirements of agricultural production before reaching a broader user-community or consumer group. The challenge is the organisation of support and the maintenance of formal as well as informal structures for knowledge and technology transfer between research and practice, and the identification of needs for action in policy relevant fields (de Smedt 2010).

In **Section II**, analysis focuses on groups of researchers which are involved in European projects aimed at integrated research for improving sustainable development in agriculture by providing knowledge from impact-assessment research to agricultural practice and policy. A provision of decision-support to policy makers through methods and instruments that convey value-perceptions of stakeholders is described as characteristic for integration and implementation sciences in action (Bammer 2005). Both case studies were typical in that the research consortium had to develop coordinating mechanisms for an integration of disciplines involved in research for sustainable development, thereby spanning from district to the European level. The case studies were also selected to represent consortia that address both the agricultural sector (e.g. via consultants concerned with agricultural development), as well as the policy sector (e.g. via consultants concerned with policy development). In both case studies, the unit of analysis was the project consortium of researchers. Research was conducted in the frame of two European Commission funded networks, namely:

Case Study 5) SENSOR IP: Sustainability Impact Assessment: Tools for Environmental, Social and Economic Effects of Multifunctional Land Use in European Regions (2004–2009), and

Case Study 6) LIAISE NoE: Linking Impact Assessment Instruments to Sustainability Expertise (2009–2014).

Innovation processes organised by research are found to deviate in functional management as compared to processes in business management. By adapting the Competing Values Framework (Quinn, 1988; Quinn and Rohrbaugh, 1983) to the requirements of a temporary transdisciplinary research project, four essential functions of project management describe the coordination processes within an inter- and transdisciplinary research project conducted at European level (**Chapter 2.4**). The functions include the development of an interdisciplinary culture within the research team, research output in the form of integrative product development, expansion and transformation via open systems, and consolidated internal processes. The example of IP SENSOR (Case Study 5) shows that managerial functions in innovation processes organised by research consortia transpire according to an inverted timeline focus.

Managerial functions are oriented both towards the external system (e.g. customers) and the internal system (e.g. the innovating team). In industry, managerial functions with an external focus are conducted in the short-term, whereas managerial functions with an internal focus are conducted in the long-term. For example, goal clarification (directing function), profit maximisation (producer function), resource acquisition (brokering function) and innovation adaptation (innovator function) have an external focus and are supported by short-term strategies. Mentoring, facilitation, monitoring and coordination functions need to be long-term to establish stability, continuity and commitment as preconditions for achieving market share. In a project-based, publicly-funded research consortium with a temporal limitation and ambition to react to questions relevant to the public, managerial functions focusing on the internal system, such as team-development and knowledge-management, are performed in the short term (generally 3–5 years). Managerial functions that focus on the external system, such as building of networks, goal clarification, accomplishment and impact, are distributed over longer timelines as these activities are coupled to reputation and positioning within the research community.

The deployment of managerial functions along the timeline defines the sequence of managerial steps applied to the innovation process (Macher & Richman 2004). The innovation process therefore follows a distinct pattern that depends on who is responsible for the organisation of the process. Ideally, a cyclic performance of managerial functions would apply to the innovation process. This would maintain a space for constant co-creation and co-evolutionary development through oscillation between the two timeline-related conceptual understandings of managerial functions.

In the example of EiCare (Case Study 3) and HayHeat (Case Study 4), a cyclic administration of managerial functions is observed due to a specific change in the organisational structure of the project consortium. This change in organisational structure stems from the policy-driven requirement to include agricultural practitioners. The main coordinators of the innovation representing agricultural practice in the form of non-scientific organisations were thus included into the organisational structure of the project consortium. The project consortium was assigned to accompany the innovation processes over a duration of five years. The integration of agricultural practice into the organisational level was set up via an additional work package, along the same line of funding structure and frame conditions as the work packages of the rest of the consortium (i.e. the researchers). The managerial functions were fulfilled by ongoing relationship interaction, implemented by regular management meetings, reflection of processes and goals as well as the joint definition of tasks and output via "boundary management" (Kueffer & Hirsch Hadorn 2008). It was observed that an organisational structure that considers research and agricultural practice on equal terms effectively provides for a constant re-arrangement of managerial functions and their timeline-related goals. Constant negotiation between agricultural practice and research takes place to discuss the priority and adequate handling of activities in line with the expectations of actors involved (Leeuwis 2000).

The constant negotiation between agricultural practice and research also ensures constructive negotiation between market-driven activities, such as consumer-orientation and value-creation, and activities that warrant a contribution to sustainability, such as the communication of compensatory properties and services to the agro-ecosystem. Where the organisational level is dominated by research actors only, as in IP SENSOR (Case Study 5) and LIAISE NOE (Case Study 6), the emphasis is on positive and negative impacts of activities on agro-ecosystems, albeit without noteworthy feasibility checks and disregarding actor-related criteria such as acceptance and adoption potential. Where the organisational level is defined by the exchange between agricultural practice and research, such as in EiCare (Case Study 3) and HayHeat (Case Study 4), this shortcoming is inherently remedied. However, weak representation of the policy spiral also has an effect at the organisational level. With reference to the managerial functions described above, it is observed that the lack of policy representation leads to a neglect of activities that safeguard a reliable contribution to innovation processes from such organisational structures. Such activities are related to the internal system, with a focus on the long-term. They would include managerial functions directed at the clarification of the services provided and the durability of the organisational structure. Furthermore, it leads to a lack of activities that address the political-frame conditions, such as official regulations. Such activities are related to the external system, again with a focus on the long term. The activities would include managerial functions directed at planning security, e.g. through standardisation, access to finances and support as well as the integration of the sustainability benefits offered by the innovation as a political goal.

An integration of policy actors as equals at an organisational level is not foreseen in current funding structures of research consortia. Generally, the role of policy is confined to acting as the coordinators and providers of funding and access to technical support. Therefore, the actors who define the organisational level need to make an extra effort to bridge agricultural practice and policy, and to communicate the outcome in a condensed and policy-relevant format. Intermediate steps comprise the mapping of existing framework conditions (e.g. regulations, standards, formal and informal market requirements), the assessment of potential positive and negative impacts of sustainability-oriented innovations (thereby considering the substantive foci and their contribution to the agro-ecosystem), and the re-structuring and prioritisation of information and data for targeted communication. In the example of EiCare (Case Study 3), it is observable that the contribution to the agro-ecosystem comprises several aspects (**Fig. 4**). In order to translate this into a competitive advantage, end-users (represented by policy) have to buy into the full range of benefits. For policy to act upon it, and to create top-down support, demand has to be actively created.

In the absence of large-scale, top-down policy support for sustainable agro-ecosystems, farmers who implement innovations depend on formal and informal relationships such as families and extension services for subsidising switching costs, as well as farmers associations and research organisations for technical information exchange (Manson et al. 2016; Nelson et al. 2014). The economic challenge faced by agricultural practice is related to the further improvement and expansion of alternative production systems to achieve market relevance and independence from subsidies. Temporary projects organised mainly by representatives of research only partly fulfil the requirement of a durable enabler of interaction between the three spirals of agricultural practice, research and policy. On the one hand, they can act as a resource for organisation and management at the organisational level of THIS. On the other hand, long-term commitments refute the self-conception of research organisations, thus highlighting a re-occurring need for the design of integrative structures in every new project for the purpose of organising relevant and context-specific research results. The question is then: what type of organisational structure is required to uphold the required managerial functions in an innovation process?

In **Chapter 2.5**, possible organisational structures are compared with the example of LIAISE NoE (Case Study 6) by applying a framework for analysing aspects of coordination within research networks (Hessels 2013). The potential for durable maintenance beyond the funded phase of the project is analysed based on participatory observation and surveys among the researchers involved in the network consortium. Thus, the value perceptions and preferences of researchers in the project consortium to retain managerial functions in the long-term were taken into consideration.

The results first of all confirm the effectiveness of project consortia as a resource for knowledge provision and scientific expertise in the development and assessment of innovative approaches for the duration of the funding period. The network structure is appreciated by the researchers, as are the benefits and the outputs that result from cooperation, synergy and complementary activities. Project consortia on the one hand provide legitimisation for researchers to be involved in activities beyond the research domain, such as consultation, brokerage and experimental development. The temporary nature of research projects sets project-based research networks apart from institutionalised brokers and intermediaries, giving particular relevance to the field of activities addressed. On the other hand, they provide an environment that is open to an involvement of users and practitioners, but closed to the claims and demands of commercialisation and market requirements. The researchers involved in the project consortium gain from stable multilateral relationships that can be utilised even after the project terminates. This provides a space for creative development and exploration. In comparing the options for long term durability, however, considerable barriers exist. Next to technical issues regarding the design and formation of a durable structure and the uncertainty that goes with it, the main barrier is found to be based upon cultural norms of the researchers. It is observed that the temporary project network is in fact the preferred form of interaction while organisational structures that move away from public funding and towards a more client-oriented consultation are rejected by the researchers in the LIAISE NoE.

This result suggests that collaborative innovation networks cannot be deliberately established as system-like organisations. Researchers build on the design and functional purpose of short-term collaborations, and thereby take advantage of the creation of a specific "project economy" (Smorodinskaya et al. 2017). Thereby, the willingness to spend time on user-interaction is found to be a good indicator of the value researchers assign to knowledge and technology transfer. However, only an integration of representatives from policy at the organisational level can ensure that the output of such collaborations is integrated into regulatory approaches that achieve longevity and durability as well as stability in the frame conditions for planning security (**Table 3**, third column). The innovation process must therefore be accompanied by frameworks and approaches for governance to achieve the frame conditions required by sustainability-oriented innovations.

3.4 Governance Level of Interactions in Sustainability-oriented Innovation Processes

Market relevance of sustainability-oriented innovations is coupled with favourable frame conditions in policy and governance that support value creation from production processes that have a positive impact on agro-ecosystems. Where the sustainability aspects of an innovation cannot be experienced by market participants directly via economic benefits, only profitable and cost-effective regulatory frame conditions can enable the innovation to move out of its niche, and to achieve viable market share. Communication of positive and negative benefits of sustainability-oriented innovations in THIS is achieved via the up-translation of substantive foci to political goals via criteria and indicators. With a declared weakness of the policy spiral at the technological and organisational level, the information, however, needs to be actively sourced and brought into the decision-making processes. The outcome needs to feed back into governance and regulation. Frameworks are required that evaluate sustainability-oriented changes, and integrate respective objectives into decision-making processes.

The decision to use impact assessment in the preparation of policy proposals was announced by the European Commission in 2002 and has been used from 2005 onwards for all proposals in the Commission's Legislative and Work Programme (Meuwese 2012; 2008). The basic rationale is to assess the appropriateness of intervening at EU-level and to assess the potential economic, social and environmental outcomes of policy changes. The initial intention was to address the lack of "evidence-based decision making" in the EU legislative process (Meuwese 2008). According to Adelle & Weiland (2012) the concept of policy assessment in Europe and in other OECD countries was driven by three trends:

- the need for an assessment scheme to deal with "big issues",
- the rise of better regulation of the political agenda,
- the integration of environmental objectives into policy-making to achieve sustainability.

In regard to the latter, the debate in the past five years has centred on the concept of ecosystem services (ESS) which provides framing for environmental concerns in ecological, socio-economic and cultural terms (Braat and De Groot, 2012; TEEB, 2010; 2011). The concept is being put forward as a cross-cutting scheme for decision-making support. Much of the subsequent conceptual development of the concept for decision-making is based on the Millennium Ecosystem Assessment (MEA) that was called for by the United Nations in 2000 and supported by 1360 experts from 95 countries (MEA 2005; Baker et al., 2013; Carpenter et al., 2006). Its application at European policy level has the overarching goal to synthesise information about environmental status and trends, as well as the dependence of human well-being on natural capital, ecosystems and the services they provide.

The proposition to use the ESS concept in integrated impact assessment (IA) of policies in the European Commission is met by an environment of competing problem frames, contested policy objectives and a multitude of interested actors. It can be used as an example in the discussion of the potential in the decision-making process for interaction between agricultural practice, research and policy.

In **Section III**, the governance level of an innovation process is analysed with the example of the European Commission policy impact assessment (EC IA). An overview of the European Commission impact assessment in relation to the process of policy development is illustrated in **Box 1**. This case study was selected due to an ongoing scientific debate on whether or not processes of impact assessment are capable of promoting interaction between the three spirals of agricultural practice, research and policy for sustainable development (e.g. Nykvist and Nilsson 2009; Adelle and Weiland 2012). Limitations are found for example in the mechanistic, deterministic and often linear linkages from land-use change to social, economic and environmental impact indicators (Helming et al. 2013). Furthermore, the European decision-making level is particularly strong in its influence on agriculture and other land-use related sectors in terms of regulatory activities and financial instruments.

Case Study 7) EC IA: European Commission *ex ante* Policy Impact Assessment (2014)

The ability of the European Commission *ex ante* Policy Impact Assessment Process (EC IA) was analysed for its ability to aid a comprehensive assessment of framework legislation and policies, and whether the use of the ESS concept would improve the integration of environmental objectives to achieve sustainability. The analysis focused on conceptual, technical, ethical and pragmatic aspects of the EC IA (**Chapter 2.6**).

The results show that the ESS concept can be adapted to several possible decision making steps in the process of policy development and policy assessment. The concept provides a set of indicators that is applicable on multiple levels of aggregation from local to global scale, and can thus be applied to support the up- and down-translation of sustainability impacts. The application of this given set of indicators furthermore supports comparative analysis between regions, sectors and time frames. The emphasis lies on a further development of the ESS concept along two operational pathways: the application of the concept for a comprehensive approach at a higher level of abstraction (soft application), and the application of the concept for providing aggregated, quantitative and unit-based information at different steps of an IA (hard application). The soft application of an ESS assessment implies a comprehensive learning approach, building on a variety of methods at different scales, and for various types of decision-support at different times during the policy-development process. Communication between actors and translation of expert knowledge to scenarios and options is the main focus in soft application. Hard application in contrast provides quantitative and unit-based information on impacts. Standardisation of indicators and units, and harmonisation of measurements at each scale are important elements in the hard application of the ecosystem services framework.

Particularly the soft application of the ecosystem services concept has potential for innovation-support by acting as a methodological approach at the science-policy interface. It can lead, for example, to a joint development of aggregated indicators, or suitable valuation and monitoring approaches that capture the positive contributions of ecosystem-based resources to sustainability. Furthermore, it supports the adaptation of policy processes to the requirements of the innovation system against the requirements of the market environment on the one side and the bio-physical environment on the other side.

The precondition to use ESS in the assessment of sustainability-oriented innovations is an existing process for the involvement of actors at the governance level (**Fig. 5, Box 1**). In this context, the EC IA process provides for an institutional structure and agency of actors to be involved based on their resources and competencies (Klerkx et al 2010). ESS can thus be applied to explain benefits to the ecosystem, and to translate sustainability from there to the European level during steps of data assimilation (**Table 3**, fourth column).

In THIS, the innovation process starts at the technological level, and sustainability is translated from the level of the substantive local focus to the global level of overarching sustainability goals (e.g. SDGs). In this context, the ESS concept can be integrated into the THIS framework, particularly for up- and down-scaling, comparative analysis, and innovative methodological approaches (**Chapter2.6**).

Box 1

Case study 7: The European Commission impact assessment process

The IA is an iterative process in which stakeholders and the public provide feedback via consultation with expert groups and internet-based public consultation. Expertise can be stakeholder representatives (organisations or Member States' authorities), scientific experts (decentralised EU agencies, scientific committees set up by the Commission, Joint Research Centres), consultants (individual providers of input) and stakeholders (specific interest groups such as citizens, consumers, workers, enterprises, public authorities or third countries).

The IA process can be illustrated along three phases, each with different demands regarding communication and knowledge transfer (Fig. 5).

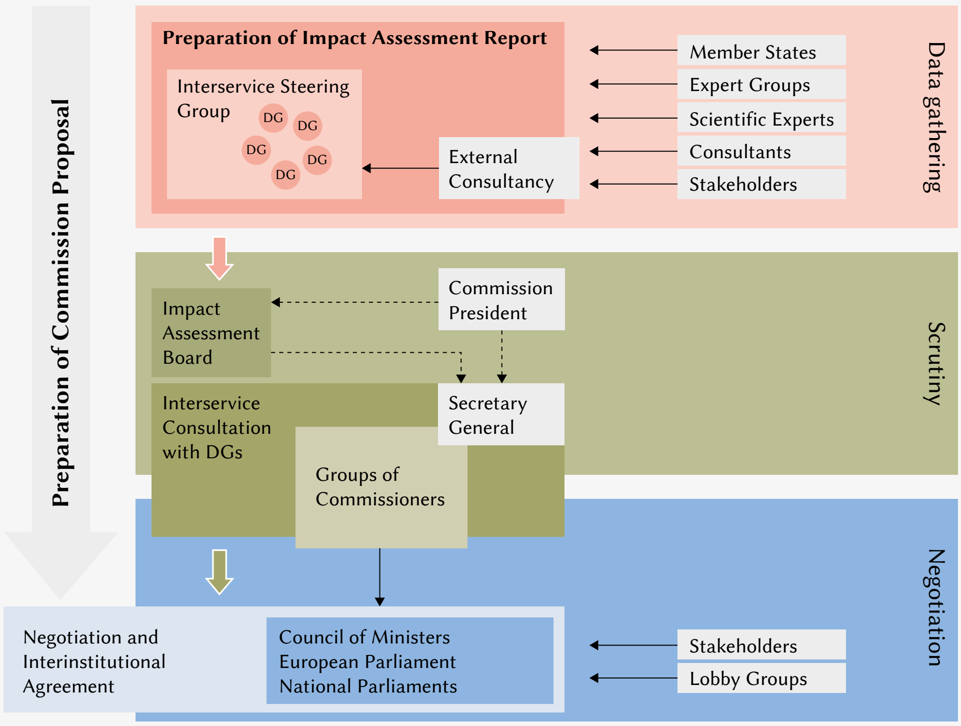

Fig. 5 The European Commission Impact Assessment Process. (EC Guidelines on Impact Assessment 2017, Robertson 2008 and Meuwese 2008, p.37, Fig. II.1).

1.Phase: Dialogue

One Directorate General (DG) takes the lead in the initiative and prepares a roadmap in dialogue with the Council of Ministers and the European Parliament. The roadmap informs other DGs, Member States and European Parliamentarians. The preparation of the impact assessment is guided by an Inter-Service Steering Group with other DGs in order to ensure consistency with other policies as well as cross-cutting perspectives. The collection of expertise and data involves all relevant Commission services and consultation from all interested and relevant parties. The impact assessment can be supported by external consultancy. The lead DG then submits the draft impact assessment report to the Impact Assessment Board.

Phase: Scrutiny

The Impact Assessment Board is an independent body appointed by the Commission President. The Board is chaired by the Deputy Secretary General and consists of senior officials drawn from cross-cutting areas of Commission. The IA Board offers recommendations and can ask for resubmission before the impact assessment report is delivered for inter-service consultation alongside the draft proposal. The IA report at this stage may also be discussed by one or more Groups of Commissioners that consist of DG directors. They are appointed by the Commission President and supported in their work by the Secretary General. The Impact Assessment Report is transmitted to the Council of Ministers and the European Parliament together with the proposal and the Explanatory Memorandum.

Phase: Negotiation

The European Parliament examines the Commission's proposal and may adopt or amend it. The Council of Ministers may decide to accept Parliament's decision or amend the position and return the proposal for a second reading. In this phase of the legislative procedure, opinions are collected from concerned parties. Amendments to the proposal can be tabled by a political group or the Ministers of European Parliament (MEP). Public hearings may take place and committee meetings are web-streamed. The impact assessment report is sent to other institutions to provide background data and information, and to allow Member States and MEPs to see the evidence which the Commission considered in its decision to proceed. Since each institution is responsible for its own impact assessment work, the Council and the Parliament can carry out further impact assessments on so-called "substantive amendments".

3.5 THIS applied to the Management of an Innovation Process

Drivers for innovation in agriculture are found in external trends such as structural change and consumer trends, in production changes towards mechanisation and rationalisation as well as in specific technical changes such as genetic modification or precision agriculture. Global competition is one of the central catalysts for innovation next to actors from upstream suppliers and scientific research (Bokelmann et al. 2012). A shift towards business and market-orientation in agriculture encourages farmers to become more market-oriented. Consequently, farmers experience similar constraints as small and medium enterprises (SMEs), including market failures, information asymmetries and imperfections in competencies (Klerkx and Leeuwis 2008). Compared to SMEs, however, entrepreneurship in agriculture does not profit from the same quality of established support structures that improve financial accessibility to different types of support measures for innovation and growth (subsidisation, insurance, tax, etc.) at sector and region levels. Ecological risks adding to the described financial risks, innovation management becomes especially uncertain and complex.

In the case studies described, value creation is not achieved, due to the actors' disregard of cost-efficient approaches such as intensification or economies of scale. This notion is driven by the motivation to implement new systems of production for sustainable agro-ecosystems. The findings show that where lack of policy input leads to a lack of measures that balance identified weaknesses in the conditions of competition.

THIS offers a framework for a balanced interaction between agricultural practice, research and policy throughout an innovation process. The results of this study highlight that extra efforts are required to include policy into the technological and organisational levels in order to achieve

- an integration of sustainability into technological development at the local production level,
- durable organisational structures for cyclic reflexive management for an accelerated and fluid organisation of the innovation process.

In policy impact assessment, the integration of sustainability via organisational structures exists for example in the EC IA (Case Study 7). New policies can be viewed as innovations at governance level. Established and institutionalised structures maintain that each new policy is evaluated from the different perspectives of agricultural practice, research and policy. Foresight-related research studies have succeeded in bringing environmental issues to the forefront of decision-making by providing criteria and indicators for policy relevant assessments, but also methods and tools for the translation and integration of (environmental) sustainability into the establishment of political agendas. Characteristics and features of technology foresight, as defined by Miles et al. (2008, p.14) include

- Informing ongoing decision-making based on the assumption that the future can be shaped in positive ways by an improved understanding of options and risks, driving forces and underlying processes of change,
- Application of formal tools and techniques in long-term analysis,
- Involvement of scientific as well as non-scientific expertise via participation, engagement in the policy process and building of networks,
- Crossing disciplinary boundaries to address real-world problems.

In an attempt to establish such structures for innovations at the technological level (product innovations, process innovations, marketing innovations), experiences from EC IA provide useful experience.

The evolution of impact assessment as a policy tool is closely related to the advance of the sustainability concept and the abundance of environmental and developmental policy goals associated with it. The first global computer simulation model for integrated assessment was developed in the 1970s in the context of the report from the Club of Rome, thus inspiring numerous models focusing on resource depletion, population and pollution (Rotmans and van Asselt 2002). The results brought attention to complex problems bearing on the survival of societies such as environmental degradation and the links with economic decline, a changing climate and the consumption of agricultural land. In response to political reflection on future development, the Brundtland report (WCED 1987) brought sustainable development onto the political agenda. The WCED defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their needs". The concept of sustainability has since become the foundation of Agenda 21 and the Rio Declaration on Environment and Development (Abaza and Baranzine 2002).

The role of the business sector was pivotal in the emergence of impact assessment as a policy development tool. Resentment among US-industrial interest groups over regulatory costs of newly-passed environmental legislation led the Nixon administration to adopt the first regulatory impact assessment in 1971 (Renda 2006). The subsequent focus on better regulation and policy efficiency did, however, impede the effort to create a balanced impact analysis of environmental, social and economic sustainability (Jacob & Hertin 2007).

Today, impact assessment is widely used in OECD countries (Adelle and Weiland 2012). The development of policy processes in the European Commission has strongly contributed to this development. The European Council agreed on the implementation of a European strategy for sustainable development in 2001. At the same time, the European Commission was determined to employ new instruments within the policy-making process in order to achieve the policy goals set down in the Lisbon Agenda (Bäcklund 2009; Renda 2006). *Ex ante* policy assessment was introduced as a means to direct targeted policy measures and identify potential environmental, social and economic impacts of the policy previous to actual implementation. The impacts were to be identified at local, regional and national level as well as in the European Union as a whole.

In the course of refining the impact assessment procedures, access to evidence-based information was called for by policy makers. Particularly the European Framework Programme, the European Union's main instrument for funding of research in Europe, triggered the development of impact-assessment tools. Overall, 203 European projects were funded in the years between 2002 and 2011. Of these, 48 projects targeted the agriculture sector (Podhora et al. 2013).

Integrated impact assessment tools were developed with a strong focus on environmental and land-use related issues (Helming et al. 2012; Schaldach and Priess 2008). Compared to earlier disciplinary approaches, these tools provided substantial improvement in the understanding of coupled human-environmental systems by addressing prospective analysis across disciplines, sectors and sustainability dimensions. In essence, they all intended to cover three basic questions:

- What kind of land-use changes are to be expected as a consequence of policy intervention?
- Where would the expected changes take place and what environmental, social and economic effects would they induce?
- Would the expected effects matter in terms of sustainable development?

Linked quantitative models were tested alongside qualitative participatory approaches (e.g. Helming et al. 2011 a, b). The literature that evolved from these projects shows the complementary advantage of using both approaches simultaneously. While quantitative models made possible the simultaneous consideration of detailed and sector-relevant information in a comparable and reproducible way, the qualitative models allowed for sound stakeholder-based valuation and knowledge transfer.

The European Commission Impact Assessment Process (EC IA) is an example of a triple-helix system that has been institutionalised into European Union policy-making. The examples shown at technological and organisational levels reveal where innovation processes run the risk of failing. The cause can lie in the imbalance between spirals or in the absence of data, but also in the absence of engagement and volition. The integration of policy at all levels is the central requirement. Only in the consideration of sustainability by all three spirals, and in the translation from the substantive, local focus to the global level is it possible to facilitate sustainability-oriented innovation towards market sustenance.

It is argued, however, that policy analysis and policy-oriented analysis alone has not been sufficient to change agricultural management. Reasons lie in poor diagnostic power in measurements of economic impact, legitimacy in the face of the dominant paradigm of economic assessment, and shortfalls in assessment that rely on scientific knowledge as the only source of expertise (Fischer et al. 2012; Lee 2006; Hall et al. 2003). An orientation towards the innovation system framework is believed to offer new ways for addressing societal goals and cross-cutting targets of sustainable development.

With the emergence of the knowledge-economy in industrialised countries, agriculture is currently changing into a "regime of ecologic knowledge". Big-data approaches and precision farming attempt to make use of this knowledge for improved site-specific changes in agricultural production. However, such approaches are characterised by a high dependency on expert knowledge, by uncontrolled effects to the value chain over time (e.g. due to changing paradigms) and by questions of the affordability of achieving sustainability, depending on societal priorities and goals. It is observed in the case studies that it is not possible to standardise management approaches due to these locally-dependent frame conditions. The question is whether the triple-helix approaches can respond to the challenges posed by this development.

THIS therefore intends to cover three basic questions:

- What are the benefits of a sustainability-oriented innovation?
- What type of organisation can support the innovation to achieve a durable impact?
- To what end shall the innovation be developed?

Applying THIS to an innovation process shows that policy needs to be included into technological and organisational levels of innovation management. This can be understood as an inverted process compared to what has developed for example in EC IA. There, methods and approaches aim to integrate agricultural practice and research at the governance level in order to achieve more adequate policies. In innovation management, methods and approaches are required that institutionalise structures for policy to involve all levels and all stages of development (**Table 3**).

Successful examples of applying a triple-helix approach in this inverted way are being developed (see **Box 2** for an example in Japan). It is shown that there is potential to establish institutionalised processes that, similarly to EC IA, include phases of data assimilation, scrutiny and negotiation for systemic changes based on informed decision-making across domains (Fishkin et al. 2017; Isernia & Fishkin 2014; Luskin et al. 1999). It is, however, crucial that this is supported at the highest levels of governance, and that policy takes the lead in organising such processes.

The disadvantage of assigning the policy sector with the responsibility of conducting a triple-helix approach at all relevant levels is the “political half-life” of politicians. The example of the Japanese decision to change from nuclear energy to alternative approaches exemplifies the vulnerability of integrated decisions (**Box 2**). However, in the case studies observed in this study, the lack of policy involvement leads to a discontinuation of the innovation process in much earlier stages. This gives rise to the appearance of innovation processes being impeded by insufficient competitive capacities, while at the same time, all actors involved work towards the articulated societal requirement for sustainable agro-ecosystems.

The apparent contradiction in sustainability-oriented innovations failing in the market environment is found to challenge democratic processes of decision-making. Suggestions in triple helix research have been made in this context to include a fourth helix for the civil society (Carayannis & Campbell 2012), and even a fifth helix to represent the perspective of the natural environments of society (Carayannis & Campbell 2010). Etzkowitz and Zhou (2006), in contrast, propose to incorporate a complementary triple helix consisting of university-government-public (for cooperation on sustainability issues) additional to the triple helix of university-industry-government (for cooperation on innovation). The authors argue that a fourth helix might cause the model to lose its creative dynamic, while the triple helix twins generate a balance in development. The proposal was, however, not further developed. Furthermore, it is not tested for its applicability to show, for example, how the communication between the triple helix twins would be organised.

In THIS, the negotiation process is an integrated but pivotal process where the democratic aspect is expressed by the interaction of actors at the different levels of the innovation process. At the technological level, these were organised by research, and resulted in the definition of sustainability aspects at the local level (substantive foci). At the organisational level, the negotiation process was driven by the inclusion of agricultural practice as an equal partner in the funding structure of the project, and resulted in a constant reflection of activities and goals (translation process from local to global level). At the governance level, negotiation was integrated into a fixed process of political representation via regional and sectoral representatives as well as experts and studies.

Box 2

Example of a triple helix decision process in Japan

In June 2012, the Prime minister from the Democratic Party of Japan decided to organise a nation-wide inquiry on the future of nuclear energy in Japan. It considered necessary that the Japanese public reach an informed decision about nuclear energy as a basis for a new energy policy. Kobayashi Tadashi and other specialists under the direction of Sone Yasunoriad organised in a few weeks a National Deliberative Poll. Registered voters (6,849) were selected at random and from them 285 participants were selected as a representative sample of this group according to their demographic, geographic, social, and educational background. The participants met at Keio University, Tokyo, on 4 to 5 August 2012. Following rigorously James Fishkin's procedure (CDD 2012), the result was a typical case of 'informed decision': between 60% and 70% of the participants declared supporting 'a society less dependent on nuclear power plants' (Kobayashi 2012). Based on this study, the Japanese government decided on 14 September 2012 to end all nuclear energy production by 2030.

But the government changed three months later: the new prime minister objected to the study, which justified the decision of its predecessor, and announced that his government would restart all nuclear plants when in agreement with the safety regulations established after the accident. But what matters is different and reinforces my argument: a nation-wide helix agreement has been reached in Japan. This agreement associates a majority of civil society, politicians and members of the administration at the national and local level, members of the academic community, and a large number of business people, from the media to high technology. This aggregate is a political arrangement between different helixes, like a reshaped DNA in an advanced industrial nation. The message is clear: a new and extended version of the helix theory is potentially, already, at work at the core of our social and economic systems.

References: citing CDD 2012, Kobayashi 2012 in Rieu 2014

Table 3 Requirements at the Technological, Organisational and Governance Levels resulting from using THIS.

THIS criteria	**Resulting gaps and structure in case studies**		
	Technological level	**Organisational level**	**Governance level**
Three predefined spirals 1. agricultural practice 2. research 3. policy	1. Agricultural practice is invested, in part as inventors, 2. Research is supported, in part as carriers of innovation, 3. Policy is lacking, its function is taken over by intermediate organisations (e.g farmers organisation, traders organisation).	1. Agricultural practice is involved as a partner, 2. Research is supported as coordinators, 3. Policy is weak, and involved as an investor only.	1. Agricultural practice is involved by representatives of organisations, 2. Research is involved via experts and studies, 3. Policy is involved via specialist departments, e.g. Directorate Generals in the European Commission and representatives of European countries and regions.
Management requirements for the balancing of spirals.	Agricultural practice and research representatives have a natural interest to involve in development. The lack of policy involvement leads to an imbalance between spirals.	Research representatives have an interest to involve in funded structures. Involvement of agricultural practice depends on availability of funding. Representatives from policy are *per se* not involved in funded structures.	All actors are involved via a specific process determined by policy (see Box 1).
Integration of sustainability aspects	Policy integration is required to translate Sustainable Development Goals (SDGS) to the local structure. This function is taken over by research in the case studies, where policy is not involved.	Policy integration is required to negotiate target goals. In the case studies, this function is taken over by research.	A fixed process scheme is available (see Box 1), organised by policy. Negotiation of target goals is deliberately included in the process to involve agricultural practice and research via stakeholder groups, experts and studies.
Estimation of positive and negative benefits from sustainability-oriented innovations	A straightforward calculation of positive impacts from sustainability-oriented innovations is not possible due to a lacking translation of sustainability impacts to the ecosystem level. The replacement effect against conventional farming can be employed as an auxiliary factor.	With policy not involved, the estimation of benefits depends on the ability and the engagement of the substituting actor groups, who take on various functions: a) the estimation of benefits from the sustainability-oriented innovation, b) the organisation of the negotiation process between all actors.	Benefits are condensed into an impact assessment report by policy (lead by the assigned department).

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4
Conclusion

With the agricultural sector being perceived as in transition, sustainability-oriented innovations are expected to improve the sustainable development of agro-ecosystems in a market-oriented environment. The main objective of this thesis is to assess the requirements needed in the innovation system to achieve effective sustainability-oriented innovation processes.

While other approaches look at the economic values, network relationships or market failures, THIS is applied to analyse gaps and barriers in the innovation process embedded in an agro-ecosystem. The novelty of this approach lies in the theoretical linkage of the triple-helix concept and impact assessment. In applying THIS to innovation processes in agriculture, it is possible to capture the complexity and address uncertainty in sustainability-oriented innovation processes in agriculture. THIS can accelerate the innovation process through the integration of policy at the technological level. The additional input from enabled and competent decision-makers will add to the assessment of strategies and steps, and can thus be taken into account in the management of the process. Institutionalisation and standardisation are difficult to achieve, because the solutions are site-specific and dependent on the immediate skills and resources of the actors involved at the local level.

By including back-casting methods, requirements for adaptation of the innovation process to sustainability goals can be identified and described. Quantitative and qualitative data-driven analyses at point-of-time were conducted to assess the situation-specific approach and innovation process in each case study setting. The case analysis was done in retrospect, so that the key events and strategies to achieve scale can be derived from actual innovation processes.

In contrast to impact assessment approaches that have been employed to integrate agricultural practice and research into policy-framing and decision-making, it is much more difficult to institutionalise an innovation process. In each case study, the local producers had to find their own specific solutions to define the value chain. The effort to achieve separate and personalised solutions requires an additional effort in terms of time and resources, in organisation as well as in management. This has to be taken into account at the very beginning of management planning. In contrast to technology-oriented feasibility studies, pilot studies are not a suitable way to proceed, as there is no general transferable character. Standardisation is not possible as it is with technological innovations.

The results are structured along three different levels of relationship interaction, technological, organisational and governance. Different factors influence and define the interaction between agricultural practice, research and policy at each level. The following characteristics are thereby found to be specifically relevant in the agricultural sector:

a) *High dependency on expert knowledge.* Sustainability-oriented innovations require detailed knowledge-input related to information that is site- and technology-specific and specific to the production system, next to an understanding of customer demand. They bear a high risk of failure due to unknown but essential natural processes. Usability, market conformity and intended positive environmental impacts need to be taken into consideration at the early planning stages of innovation development.
b) *Uncontrolled effects to the value chain over the years and due to changing paradigms.* Input from upstream suppliers and output to retailers and customers influence not only the production chain, but have additional effects on the environmental impact of the innovation.
c) *Affordability of innovation functions as dependent on societal priorities and goals.* In a multi-dimensional agro-ecosystem, the benefit of an innovation is not only described in direct economic returns, but in terms of social or environmental benefits and public goods. The implementation of change, however, is perceived differently by the diverse sectors concerned, and the question remains, which sector would support the process financially.

Altogether, the interaction within a triple helix system allows for the participation of relevant actors at each step of decision making, mainly reflected by negotiation and discourse. THIS reveals the options and requirements to achieve pre-determined innovation-management and sustainable development goals at the initial, technological level.

In the case studies described, creation of value is not achieved where the policy spiral is weak, and where decision-makers do not propose measures that balance identified weaknesses in the conditions of competition. Foresight approaches using back-casting to improve the situation by identifying gaps at other systemic levels, and by defining criteria for sustainable development. This ultimately reduces complexity by allocating knowledge gaps to the systemic level at which they can be addressed. A gap analysis identifies the shortcomings at each level of relationship interaction. At the technological level, the gap is related to the lack of a definition of sustainability goals that can only be defined by knowledgeable representatives of policy. At the organisational level, the gap is in the durability and suitability of structures to support cyclic innovation management. At governance level, the emphasis lies on the availability of a fixed process for participation and integration of representatives from all spirals and levels. It is here, that sustainability goals are translated from the local level to the global level of sustainability. The ecosystem services concept can thereby qualify the data gathering, by supporting up- and downtranslation of sustainability benefits. Impact assessment can be applied to assess policy frame conditions and assess innovations therewithing.

It is emphasised that agricultural land use is a highly complex sector for *ex ante* assessment of potential impacts and innovation planning. Due to its links to many adjacent sectors such as tourism, nature conservation or transport, proper impact assessment requires the involvement of additional policy areas. Affected sectors and policy areas are concerned with impacts and effects at different time horizons and spatial scales, which in turn requires methods and research disciplines addressing the different levels of scale. These multiple functions of land lead to a concern of actor networks at various decision-making levels. While for example agricultural policies are increasingly determined by European policy-making, actors and stakeholders are largely embedded at the local level. Next to policy-makers and researchers, these actors include entrepreneurs, non-governmental organisations, and civil society. A divergence of interests within the system has an effect on the knowledge-transfer processes, visualisation of problem states and the translation of claims between groups of actors. The technological and organisational levels are not able to lead the process from the beginning to the end.

The gap analysis identifies the shortcomings at each level of relationship interaction. At the technological level, the gap is related to the lack of defined sustainability goals that can only be defined by knowledgeable representatives of policy. At the organisational level, the gap is in the durability and suitability of structures to support cyclic innovation management. Again, only an integration of policy into the structural frame conditions can solve this. At the governance level, the emphasis lies on the availability of a fixed process for participation and integration of representatives from all spirals and levels. It is here that sustainability goals are translated from the local level to the global level of sustainability. The concept of ecosystem services can thereby qualify the data assimilation by supporting up and down-translation of sustainability benefits. Impact assessment can be applied to assess policy-frame conditions and assess innovations therewith.

It is observed in the case studies that a local actor group alone cannot achieve a coordinated organisation of such a process, let alone sustainability. The innovation process can only be completed where governance is involved and in the lead (e.g. EC IA). Where the policy frame conditions do not support sustainability-oriented development, the case will fail. Negotiation between ecosystem-related fit, market conformity and usability need to be considered in innovation development already in the earliest planning stages. This can be done best by including policy representatives as early as possible into the process. Policy has to be enabled to involve and engage in the process via suitable organisational structures that reflect the need for iterative cycles and reflection in management. Possible pathways include time flexible projects and funding structures that include policy into the consortium of a project. Furthermore, durable organisational structures require the involvement of policy to maintain project networks beyond the funding phase of projects.

V

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The study was conducted at a time where innovation has been increasingly supported by European strategies. At the outset of this study, interdisciplinary research projects aimed at large-scale assessments of change in terms of environmental, social and economic impacts. Over the last five years, we have experienced a rising perception of persistent environmental problems due to multi-layered interrelationships between actors, sectors or countries. In consequence, innovation research at the local and regional level has increasingly been supported by European and national research funding. The development is in some ways reflected in this cumulative work conducted between 2011 and 2017. My belief in the need for creativity in face of continuous pressures on societies to adapt to change motivated me to pursue research in this field. I set out to understand “what is new”, and ended up with questions of “what is best” and “how to do it right”.

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VI

List of Publications

This dissertation is based on the following peer-reviewed papers. The following numbering reflects the order of the papers presented in this thesis.

Paper 1: **Diehl, K.**, König, B., Lentzsch, P. & S. Lundie. (*working paper*). Transition to sustainable agro-ecosystems: operationalising the sustainable development concept for four innovative case studies of multifunctional agriculture in Germany.

Paper 2: **Diehl, K.**, Rebensburg, P. & P. Lentzsch. (2013). Field application of non-pathogenic *Verticillium dahliae* genotypes for regulation of wilt in strawberry plants. American Journal of Plant Sciences, 4(7A2):24–32.

Paper 3: **Diehl, K.** (2016). Sustainability assessment of agro-ecological innovations at territorial and value chain scale. Proceedings of the 12th European IFSA Symposium on Social and technological transformation of farming systems: Diverging and converging pathways. Harper Adams University, UK, 12–15 July 2016.

Paper 4: König, B., **Diehl, K.**, Tscherning, K. & K. Helming. (2013). A framework for structuring interdisciplinary research management. Research Policy, 42(1):261–272.

Paper 5: **Diehl, K.**, Uckert, G. & J. Dick. (*submitted*). Maintaining a research network in the post-funding phase: Activity-based Model Profiles for a Durable Integration Structure.

Paper 6: **Diehl, K.**, Burkhard, B. & K. Jacob. (2016). Should the ecosystem services concept be used in European Commission impact assessment? Ecological Indicators 61:6–17.

Additional peer-reviewed publications (co-)authored in the course of this PhD-study:

Jaber, L. S., **Diehl, K. E.** & S. K. Hamadeh. (2016). Livestock and food security in the Arab region: policy framework. Food Security 8(5):899–908. DOI: 10.1007/s12571-016-0608-4

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SENSOR IP: Sustainability impact assessment: Tools for environmental, social and economic effects of multifunctional land use in European regions. Funded by DG Research, 6th Framework Programme, December 2004–May 2009. Coordination: Dr. Katharina Helming (ZALF).

TRANSPLORE: Implementation and Professionalisation of a valorisation concept for research transfer at the Leibniz Centre for Agricultural Landscape Research. Funded by the Federal Ministry of the Interior (BMI), Science meets Business Initiative, July 2009–June 2011 (TRANSPLORE I); the Federal Ministry of Education and Research (BMBF), July 2011–June 2014 (TRANSPLORE II) and July 2014–June 2017 (TRANSPLORE III). Coordination: Katharina Diehl (ZALF).

COPAL: Innovative approaches for knowledge and technology transfer from agricultural sciences and research through supra-organisational communities of practice (CoP). Funded by the Federal Ministry of the Interior (BMI), Science meets Business Initiative, July 2009–June 2011. Coordination: Dr. Reinhard Fuchs (ATB).

NoE LIAISE: Linking impact assessment with sustainability expertise. Funded by the 7th Framework Programme, Global Change and Ecosystems, November 2009–April 2014. Coordination: Prof. Dr. Klaus Jacob (FU Berlin).

PROFITECH: Professionalisation of technology transfer in the Leibniz Association. Funded by the Federal Ministry for Economic Affairs (BMWi), SIGNO Strategy, January 2010–March 2012. Coordination: Dr. Gesa Gordon (INP).

ZALFx: Technical and scientific steering of a ZALF spin-out for improved research transfer. Funded by the Federal Ministry of Education and Research (BMBF), LeibnizX and EXIST Strategy, October 2010–September 2011. Coordination: Katharina Diehl, Holger Seidler (ZALF).

EVI: Development and test of a biologic compound based on a patented method for regulation of Verticillium on strawberry plants. Funded by Landwirtschaftliche Rentenbank, April 2011–March 2013. Coordination: Katharina Diehl.

LIAISE Open: Reviewing concepts on durable relationships for research networks conducting policy impact assessment processes in the European Union. Funded by the 7th Framework Programme, Global Change and Ecosystems, March 2013–April 2014. Coordination: Katharina Diehl.

GINKOO: Designing integrative innovation processess: New institutional and regional forms of coordination for sustainable land management. Funded by the Federal Ministry of Education and Research (BMBF), November 2015–Oktober 2018. Coordination: Dr. Bettina König (HU Berlin).

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Consultancy and application of scientific research

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VII
Summary

Sustainability-oriented innovation supports efficiency in the use of natural resources and mitigation of negative environmental impacts. While aiming to achieve an expected environmental benefit alongside to entrepreneurial success, such innovation is less likely to be successfully adopted in a market environment due to greater financial uncertainty in connection with ecological risks.

The overall objective of this study is to analyse innovation processes in agriculture, and to assess their ability to integrate market-driven as well as ecosystem-oriented activities across different levels of relationship interaction. With innovation being a precondition for systemic change, innovation management for sustainable development has increasingly moved into the focus of research, policy and planning. This is expressed for example by targeted calls for tender in research and development that aim to channel new knowledge into practice. Distinctive trends in the use of agricultural resources, such as increased land utilisation and the detrimental influence of nutrient emissions to the environment, contribute to a mentality of social and environmental responsibility in the development of innovative approaches particularly in agriculture. Questions, however, arise in regard to the management of new types of agricultural production and distribution that are in accordance with the principles of sustainable development.

This study was conceived to overcome a domain approach in agriculture by developing a framework for the analysis and management of sustainability-oriented innovation processes in agriculture: the Triple Helix System of Innovation for Sustainability (THIS). THIS builds on triple helix approaches and innovation systems research. It is set to enhance the generation, diffusion and utilisation of new knowledge generated by interaction between agricultural practice, research and policy.

The framework was developed by analysing case studies of sustainability-oriented innovations in agriculture, and applied to structure the innovation process into different levels. From here it was possible to deduce management strategies for effective and accelerated development of innovation. Each level reveals specific research questions, addressing for example the assessment of potential sustainability impacts at the beginning of an innovation process (the front end), managerial functions required to organise and steer an innovation process, or the potential for integrating indicators for sustainability in policy regulation and governance. These questions are addressed in seven case studies and six sepa-

rate research papers presented in the results section. By including back-casting methods for *ex ante* impact assessment, requirements for adaptation of the innovation process to sustainability goals are identified and described. Quantitative and qualitative data-driven analysis at point-of-time is conducted to assess the situation-specific approach and innovation process in each case study setting. The case analysis is done in retrospect, to accomplish an analysis of the key events and strategies to achieve scale.

Overall, the balancing of actor engagement and the integration of sustainability adds extra requirements to the steering of processes that already involve complex navigation between technological development and market requirements. In detail, this means that each actor group already introduces its normative elements into the process at the beginning of the innovation process. Thus, agricultural practice is concerned with questions of feasibility and viability, while research is linked to issues of sustenance and impact, and policy for regulation. The negotiation of normative elements becomes an essential activity in achieving a comprehensive innovation process for sustainability in agro-ecosystems, and it must be coherent across the domains of agricultural practice, research and policy.

In THIS, the negotiation of sustainability goals is conducted by translating the substantive focus of innovation at the local level to the overarching global United Nations Sustainable Development Goals (SDGs). Research is conducted using case studies based on inter- and transdisciplinary research cooperation embedded in several projects. The local level is represented by four innovative initiatives in the agricultural sector in north-eastern Germany. The European level is represented by cooperative international research that aims to facilitate knowledge transfer at the science-policy-practice interface for decision-making.

To further integrate the results, and bring together the three domains of agricultural practice, research and policy in THIS, the framework was effectively divided into three levels of relationship interaction, based on a main component identified in case studies. Each level represents the main aspect of institutional relationships relevant to the negotiation of market versus ecosystem, including 1) technological, 2) organisational, and 3) governance aspects. Methods sensitive to the context of individual case studies were applied to achieve results specific to each case.

The case specific results could be structured along the technological, organisational and governance levels by using THIS. The technological development of sustainability-oriented innovation shows a lack of policy integration in the early development stages of planning, field testing and goal definition. The analysis of the organisational level with the example of interdisciplinary project management for an integration of environmental, social and economic effects of land use highlights the necessity for durable structures capable of iterative innovation management. At the governance level, the process of European Commission policy impact assessment is observed as an institutionalised process enabling a feedback loop from impact assessment to governance and policy-planning as well as sector related land use management.

In applying THIS, the innovation process is shown to require a greater presence of policy representatives at the technological and organisational levels. This could be achieved for example by broadening project funding to include policy representatives into projects. The assessment of an innovation, and reflection against the sustainability targets for agro-ecosystem and global impact, is required as an ongoing process in innovation management that requires a translation of sustainability goals to the local structure. Furthermore, the validation of positive results under consideration of ecological risks requires experimental research and testing in projects with temporal flexibility.

The gap analysis resulting from the application of THIS contributes to the debate on viable forms of innovation management for sustainability-oriented innovation. THIS provides a framework for innovation processes to address risks and to accelerate the process in the face of additional uncertainty posed particularly by environmental aspects characteristic to innovations developed in the agricultural sector. Finally, this study shows how the requirements of iterative management can be reflected in organisational structures for institutional support.

Declaration

I hereby declare that I completed the doctoral thesis independently based on the stated resources and aids. I have not applied for a doctoral degree elsewhere and do not have a corresponding doctoral degree. I have not submitted the doctoral thesis, or parts of it, to another academic institution and the thesis has not been accepted or rejected. I declare that I have acknowledged the Doctoral Degree Regulations which underlie the procedure of the Faculty of Agricultural and Horticultural Sciences (Humboldt-University), as amended on 14th July 2005. Furthermore, I declare that no collaboration with commercial doctoral degree supervisors took place, and that the principles of Humboldt-Universität zu Berlin for ensuring good academic practice were abided by.

Erklärung

Hiermit erkläre ich, die Dissertation selbstständig und nur unter Verwendung der angegebenen Hilfen und Hilfsmittel angefertigt zu haben. Ich habe mich anderwärts nicht um einen Doktorgrad beworben und besitze keinen entsprechenden Doktorgrad. Ich erkläre, dass ich die Dissertation oder Teile davon nicht bereits bei einer anderen wissenschaftlichen Einrichtung eingereicht habe und dass sie dort weder angenommen noch abgelehnt wurde. Ich erkläre die Kenntnisnahme der dem Verfahren zugrunde liegenden Promotionsordnung der Landwirtschaftlich Gärtnerischen Fakultät der Humboldt-Universität zu Berlin vom 14.07.2005. Weiterhin erkläre ich, dass keine Zusammenarbeit mit gewerblichen Promotionsbearbeiterinnen/Promotionsberatern stattgefunden hat und dass die Grundsätze der Humboldt-Universität zu Berlin zur Sicherung guter wissenschaftlicher Praxis eingehalten wurden.